MONTHLY WEATHER REVIEW

VOLUME 81 NUMBER 10

OCTOBER 1953

CONTENTS

U. S. DEPARTMENT OF COMMERCE • WEATHER BUREAU

PUBLICATIONS OF THE U. S. WEATHER BUREAU

As the national meteorological service for the United States, the Weather Bureau issues several periodicals, serials, and miscellaneous publications on weather, climate, and meteorological science as required to carry out its public service functions. The principal periodicals and serials are described on this page and on the inside of the back cover. A more complete listing of Weather Bureau publications is available upon request to Chief, U. S. Weather Bureau, Washington 25, D. C.

Orders for publications should be addressed to the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

MONTHLY WEATHER REVIEW

First published in 1872, the Monthly Weather Review serves as a medium of publication for technical contributions in the field of meteorology, principally in the branches of synoptic and applied meteorology. In addition each issue contains an article descriptive of the atmospheric circulation during the month over the Northern Hemisphere with particular reference to the effect on weather in the United States. A second article deals with some noteworthy feature of the month's weather. Illustrated. Annual subscription: Domestic, $3.50; Foreign, $4.50; 30 cents per copy. Subscription to the *Review* does not include the *Supplements* which have been issued irregularly and are for sale separately.

CLIMATOLOGICAL DATA—NATIONAL SUMMARY

This monthly publication contains climatological data such as pressure, temperature, winds, rainfall, snowfall, severe storms, floods, etc., for the United States as a whole. A short article describing the weather of the month over the United States, tables of the observational data, and a description of flood conditions are supplemented by 15 charts. An annual issue summarizes weather conditions in the United States for the year. More detailed local data are provided in the Climatological Data (by sections) for 45 sections representing each State or a group of States, and Hawaii, Alaska, and the West Indies. Subscription price for either the National Summary or for a Section: $1.50 per year (including annual issue), 15¢ per copy.

(Continued on inside back cover)

The Weather Bureau desires that the *Monthly Weather Review* serve as a medium of publication for original contributions within its field, but the publication of a contribution is not to be construed as official approval of the views expressed.

The issue for each month is published as promptly as monthly data can be assembled for preparation of the review of the weather of the month. In order to maintain the schedule with the Public Printer, no proofs will be sent to authors outside of Washington, D. C.

The printing of this publication has been approved by the Director of the Bureau of the Budget, February 11, 1952.

DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, Secretary

WEATHER BUREAU
F. W. REICHELDERFER, Chief

MONTHLY WEATHER REVIEW

Editor, JAMES E. CASKEY, JR.

Volume 81
Number 10

OCTOBER 1953

Closed December 15, 1953
Issued January 15, 1954

HIGH LEVEL VERTICAL MOTION IN RELATION TO TROPICAL RAINFALL

BANNER I. MILLER
U. S. Weather Bureau, San Antonio, Tex.

[Original manuscript received July 6, 1953; revision received October 29, 1953]

ABSTRACT

A single-station technique is used to compute vertical velocities over San Juan, P. R., at standard constant pressure levels from 850 to 100 mb. Periods of strong upward motion are observed to occur rather frequently within the layer 400 to 100 mb. and these are discussed in relation to subsequent precipitation patterns.

INTRODUCTION

During recent years, forecasting techniques in tropical and subtropical latitudes have been vastly improved, largely due to the efforts of Dunn [1], Riehl [2], and others too numerous to mention, who have developed and applied what Palmer [3] calls the perturbation method to low latitude disturbances. The identification and forecasting of the motion of easterly waves, polar troughs, shear lines, and other tropical phenoma often results in satisfactory forecasts of the accompanying weather. But frequently, identifiable changes in the wind, temperature, or pressure fields (including the isallobaric pattern) occur almost simultaneously with the onset of precipitation so that no adequate forecast can be issued.

The present study began as an effort to discover some element that would enable the forecaster to determine at least 24 hours in advance whether or not an approaching disturbance would yield significant precipitation over Puerto Rico. Conversely, it was desired to forecast accurately periods of no precipitation which might be expected to last 2 or more days.

Puerto Rico lies just within the tropical zone, and its climate is a combination of the tropical and subtropical. Showers normally occur on more than 200 days per year, so the usual forecast of partly cloudy with a few scattered showers has a better than even chance of verifying every day of the year. But such a forecast is of little value to the recipient. There are periods of prolonged shower activity which may go on for as long as 2 or 3 days with excessive rainfall amounts being recorded. There are also periods during which the sky remains almost cloudless and no showers occur for several days. Advance warning of such periods of unusual weather would be of value to the public as well as to agriculture and industry.

Since weather changes, regardless of the latitude, are intimately connected with vertical motion in the atmosphere, an attempt was made to measure this quantity and to correlate its values with subsequent weather patterns.

METHODS

The single-station technique as developed by Panofsky [4] was used to compute the vertical motion. He derived the relationship

$$\frac{\partial T}{\partial t}+\mathbf{V}\cdot\nabla T+w(\Gamma-\gamma)=0 \qquad (1)$$

where T is temperature, t is time, $\mathbf{V}$ is horizontal velocity, ∇ is the horizontal vector differential operator, w is the vertical velocity, Γ is the dry adiabatic lapse rate, and γ the prevailing lapse rate (the average between two successive constant pressure surfaces). $\frac{\partial T}{\partial t}$ was evaluated by determining the 24-hour local temperature changes at each level. A 12-hour change would have been better, but the diurnal variations were so large that obviously incorrect values resulted, and not enough data were available to establish the normal diurnal changes. However, it would seem desirable to determine such normals if further research along this line is pursued. To find $\mathbf{V}\cdot\nabla T$ from the winds aloft (radio winds are available at

San Juan so that the computations are not restricted to good weather) use was made of the relationship (see Panofsky [5])

$$\mathbf{V}\cdot\nabla T=\frac{2fT}{g}\frac{\partial A}{\partial z}, \tag{2}$$

where f is the Coriolis parameter, g is the acceleration of gravity, ∂A is the area enclosed by the vectors $\mathbf{V}$, $\mathbf{V}+d\mathbf{V}$ and $d\mathbf{V}$ on a hodograph of observed winds, and z is the vertical coordinate. The right side of (2) was evaluated by taking the wind shear between adjacent levels, i. e., 1000–850 mb., 850–700, 700–500, etc. No corrections were made for the variations of the heights of the constant pressure surface when $\frac{\partial T}{\partial t}$ was determined. However, these variations were usually small, in most cases less than 25 meters, and so only small errors were introduced. Application of this technique to more northerly latitudes where the changes in the constant pressure heights are significant would necessitate the correction of the local temperature changes for this factor.

As pointed out by Panofsky, the above method has two sources of inherent error. First, nonadiabatic processes are at work in the atmosphere, and these result in some errors in the computed vertical motion, particularly in the lower levels after precipitation starts. Second, the theory of advection from the hodograph is based on the assumption of geostrophic wind flow. This is a more serious objection than the first when the method is applied to a southerly latitude such as Puerto Rico, where it is usually assumed that the geostrophic relationship frequently does not apply. For this latter reason, the present study was undertaken with serious misgivings, and the expectations of failure were high. Actually, there were cases in which apparently supergradient winds, strong anticyclonic curvature, and cross-contour flow resulted in some computed values of vertical motion which seemed to be incorrect, but on the whole results were better than expected. The correlation between the vertical velocities and the weather changes was generally satisfactory, although the values were usually smaller, level for level, than those computed by Miller [6] and others at New York University for temperate latitudes.

The value of the Coriolis parameter at 20° N. latitude is 0.497×10^{-4} sec.$^{-1}$, or about one-half that for a latitude of 43°, and this value is not a negligible factor by any means. It appears possible that the deviation from the geostrophic balance is less at the latitude of Puerto Rico than is normally supposed. The results of the present study at a low latitude do not always agree with those made in the middle latitudes, a possibility suggested by Panofsky [7], but whether this apparent difference is real or a fault of the method of computation is questionable at this time.

RESULTS

Vertical velocities were computed at seven isobaric levels twice daily for the periods November 20–December 10, 1951; December 27, 1951–January 6, 1952; and January 27–February 14, 1952. Discussion here will be limited to the winter months, when the level of the westerly winds over Puerto Rico is relatively low. Some studies were carried out during the summer season, under conditions of predominantly deep easterly flow, but the results will not be treated at this time.

The computed vertical motions in the lower levels (850–500 mb.) were in most cases in fairly good agreement with the observed weather. That is, rising air was usually associated with increase in cloudiness, precipitation, and a steepening of the lapse rate, while descending air was accompanied by the opposite effects. However, the values of the vertical velocities were small, in most cases less than 1.0 cm. sec.$^{-1}$. The absolute average at the 700-mb. level was 0.4 cm. sec.$^{-1}$ for 117 cases. Miller [6] reported a mean absolute value of 1.4 cm. sec.$^{-1}$ at 700 mb., this value being based on 455 cases at selected points within the United States, ranging from 35° to 45°N. latitude. It is to be expected that the magnitude of the vertical motion in the Tropics or subtropics would be somewhat less than that in the middle latitudes. In addition, Miller's results were computed for 12-hour periods, while the present study is based on 24-hour intervals.

Much larger values were observed to occur in the upper layers, 400 mb. and above. The maximum was usually reached at 200 mb., where the absolute average was 3.0 cm. sec.$^{-1}$ for 112 cases. The remainder of this discussion will be confined to the high level values.

Rather large positive values of vertical velocity occurred frequently within the layer 400–100 mb. In some cases, the vertical motion was damped out after a single appearance, but the usual pattern was for the positive values to persist for several days at a time. Whenever such continuity did occur, moderate to heavy rainfall was usually observed at San Juan within 60 hours or less after the initial appearance of the upward motion in the higher levels.

In an attempt to use these upper level periods of maximum vertical velocity as a forecast tool, it was first necessary to separate the minor fluctuations from the significant centers. The following rule was therefore adopted. No value was considered significant unless it was, first, at least 1.5 cm. sec.$^{-1}$, and second, observed to occur twice in succession, but not necessarily at the same level, since there was a marked tendency for the levels of maximum vertical velocity to rise and fall. However, the two successive positive values were required to be connected, i. e. occur at adjacent levels (or at the same level if the center did not change elevation). For example, a positive value might be observed at 200 mb. and 12 hours later lower to 300 mb., a fairly frequent occurrence. There were also a few cases under which the level of maximum positive vertical motion rose with time.

After the relationship between upward motion at high levels and later shower periods became evident, it was necessary to define "significant precipitation." As previously stated, showers occur approximately 2 days out of 3 in the vicinity of San Juan, with the predominating

fall being light and of short duration. For the purpose of this study it was desired to differentiate between the "normal" and the unusual rainfall regimes, and consequently "significant rainfall" was arbitrarily defined as at least 0.50 inch in 24 hours, with the shower period lasting at least 12 hours, i. e. with rainfall being measured in at least two consecutive 6-hour periods. The average rainfall for San Juan is about 55 inches per year, so the value of 0.50 inch per day is over three times the normal daily rainfall.

Table 1 shows a summary of the cases meeting the above stipulations. Ten cases were observed. Nine of the ten cases were accompanied by significant rainfall. In the other case, that of November 25, the positive values of the vertical velocity were restricted to the 300-mb. level only, with large negative values being present at both 400 and 200 mb. throughout. The case was atypical, and appears to be an instance in which the method of computing the vertical velocities failed. The situation was marked by strong winds, apparently supergradient, and decided veering from the 400-mb. to the 300-mb. level. This resulted in apparent positive values, but they were possibly nonexistent.

In 8 of the 9 cases accompanied by precipitation, there was an appreciable time lag after the second positive value of 1.5 cm. sec.$^{-1}$ or more was observed before the rain began. In 6 of the 8 cases this time lag was 21 to 57 hours, and in the other 2 it was only 9 hours. The average lag was 30 hours; the value of such a time factor as a forecast tool is obvious.

Table 1.—*Relationship between high level vertical velocity patterns and subsequent rainfall at San Juan, P. R., November-February 1951–52*

Date and time 2d positive value of $w \geq 1.5$ cm/sec occurred	Level of 1st occurrence of positive value of $w \geq 1.5$ cm/sec	Maximum value of w observed during period	6-hour period of beginning of significant rainfall	Time lag rain began after positive value of w observed 2d time	Duration of positive values of w at level 100–400 mb ($w \geq$ 1.5 cm/sec)	Duration of significant rainfall	Total rain all during period
GMT	mb.	cm/sec	GMT	hr.	hr.	hr.	in.
1500 Nov. 20	200	5.4	0600 Nov. 22	39	84	72	3.05
1500 Nov. 25	300	4.1	Nil	----------	36	Nil	Nil
0300 Dec. 1	100	4.1	1200 Dec. 3	57	48	24	4.90
0300 Dec. 6	300	5.3	1200 Dec. 6	9	60	48	3.39
0300 Jan. 5	400	2.8	0000 Jan. 6	21	24	12	.91
1500 Jan. 7	200	4.2	0600 Jan. 9	39	84	18	1.35
0300 Jan. 12	400	3.1	0000 Jan. 12	0	24	18	.67
1500 Jan. 27	100	4.6	1800 Jan. 29	51	60	12	.84
0300 Feb. 9	300	7.4	0600 Feb. 11	51	60	24	1.83
1500 Feb. 12	300	1.6	0000 Feb. 13	9	24	36	1.86

In only one case (January 12) was rainfall observed to occur without there first having been present upward motion at some high level over the station. A single positive value was present at 400 mb. before rain began, but such occurrences cannot be considered significant until they are observed at least twice in succession. Consequently the appearance of the center of maximum positive vertical velocity over the station and the onset of precipitation must be considered approximately simultaneous.

It should also be noted that there were no cases of significant rainfall which failed either to follow closely or occur simultaneously with a period of high level upward motion.

Figures 1–3 show some typical examples. They are time cross sections over San Juan, depicting isopleths of vertical motion at intervals of 1 cm. sec.$^{-1}$, winds aloft at standard isobaric surfaces, and the rainfall measured at the 6-hourly observations.

While these figures show computations of vertical velocity only, levels of divergence and convergence may be identified from the vertical changes in the vertical motion patterns. For example, the centers of maximum positive vertical velocity are levels of zero divergence; below this level, where the vertical velocity is increasing upward, horizontal velocity convergence is taking place. Above this level of zero divergence, the vertical velocity is decreasing upward, and horizontal velocity divergence is occurring. The negative centers are likewise levels of zero divergence, with convergence above and divergence below these centers. However, the method of computation in neither case is sufficiently accurate to locate precisely, or even closely, the actual level of nondivergence.

In figure 1, the initial positive value of vertical velocity was observed at 0300 GMT, November 20, 12 hours before the time of beginning of the cross section. The value was 3.9 cm. sec.$^{-1}$ and it occurred at 200 mb. At the time of the second appearance of positive values, the maximum had lowered to 300 mb. where it was observed to be 2.2 cm. sec.$^{-1}$. Twelve hours later the maximum was again at 200 mb. where it remained until 0300 GMT, November 24, when negative values were present at this level. Significant rainfall began about 0600 GMT, November 22, (0.28 inch was measured at 1230 GMT on that date), about 39 hours after the time the maximum was observed for the second time. Showers lasted for about 72 hours, with a total accumulation of 3.05 inches.

Figure 2 reveals a similar pattern, but in this case the initial upward motion is found at 100 mb., and there is a marked tendency for the level of maximum positive vertical velocity to lower with the passage of time. This feature is also noticeable to a lesser degree in figures 1 and 3, and it should be mentioned here that this seemed to be the usual pattern. As long as the center of maximum positive vertical velocity remained at a constant high level, precipitation did not occur. But as soon as the center lowered, or small offshoots from the high level

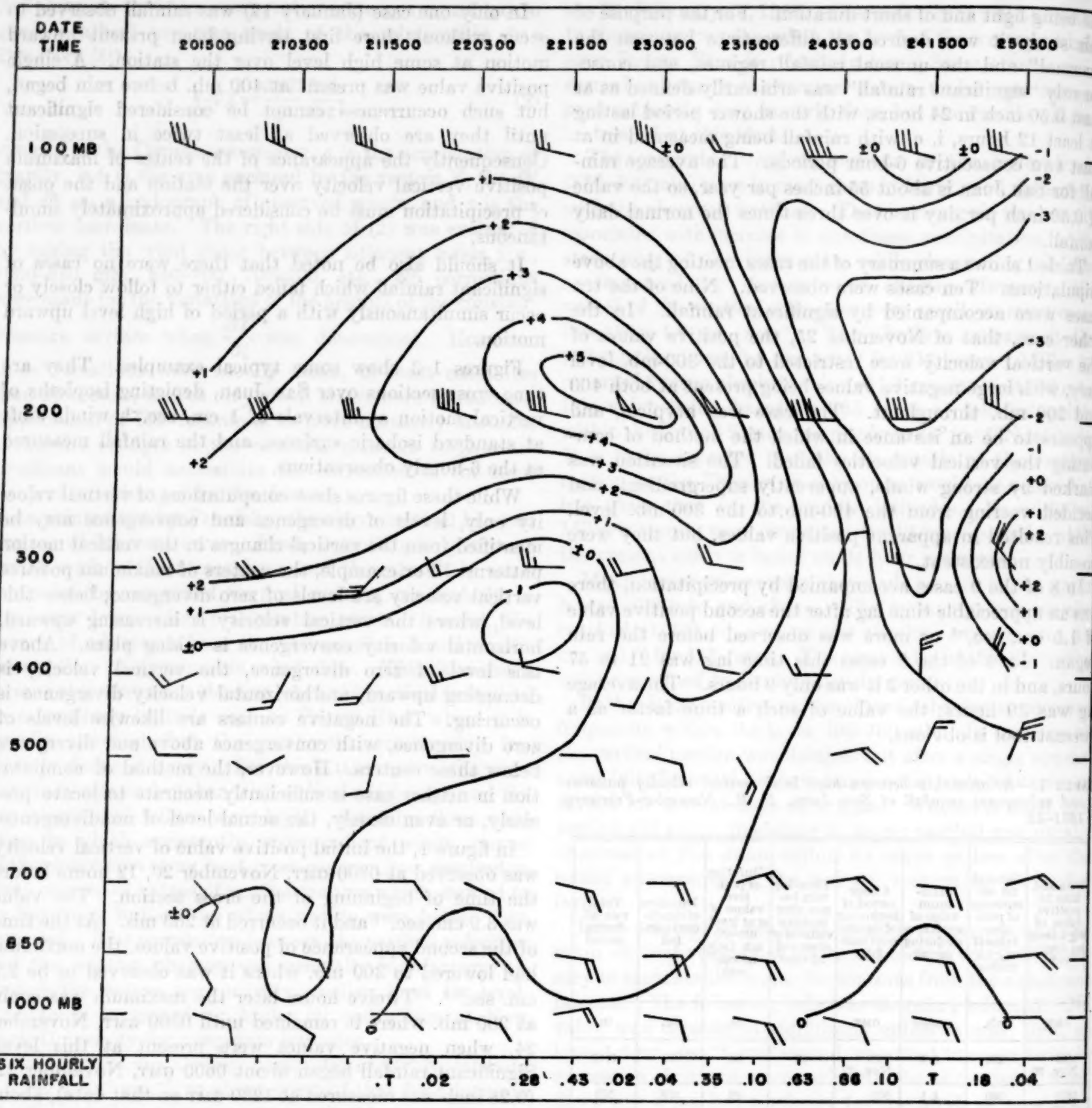


FIGURE 1.—Time cross section over San Juan, Puerto Rico, 1500 GMT November 20 to 0300 GMT November 25, 1951. Isopleths of vertical motion are indicated in cm. sec.$^{-1}$. Rainfall amounts are in inches, and wind speeds in knots.

center extended into the lower levels, early rainfall was in prospect.

In figure 3, the rising air is first in evidence at 300 mb., and throughout the history of this case a strong divergent flow persisted immediately above the upward motion. The fact that the upward motion appears at a lower level at this time of year (February 8–14) than it did earlier in the winter is perhaps a reflection of the well known tendency for the dominant features of the general circulation to appear at lower levels during the winter season.

Another interesting feature of this cross section is the reappearance of a small, secondary center of positive vertical velocity at 0300 GMT, February 12. This is almost immediately followed by heavy rain on the 13th. Perhaps during a rainy regime, less violent activity is required to cause an already existing disturbance to regenerate than would normally be required.

A comparison with the work of Graves [8] is interesting. He correlated the variations in the heights of a secondary tropopause over San Juan with the incidence of strong

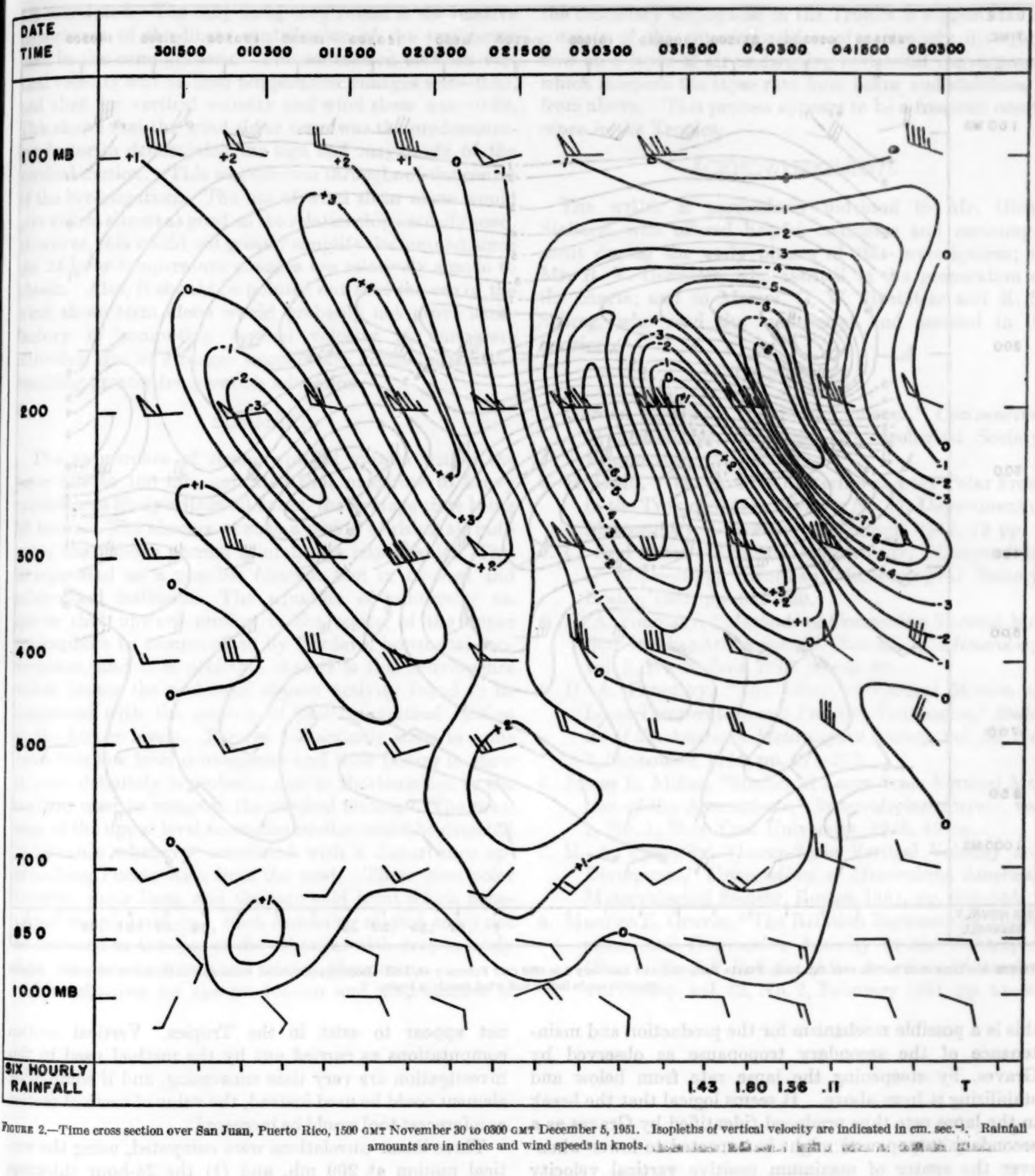


FIGURE 2.—Time cross section over San Juan, Puerto Rico, 1500 GMT November 30 to 0300 GMT December 5, 1951. Isopleths of vertical velocity are indicated in cm. sec.⁻¹. Rainfall amounts are in inches and wind speeds in knots.

convective activity over Puerto Rico. He found that the existence of a rising secondary indicated that severe convection was unlikely within 48 hours, and that a lowering secondary favored its occurrence.

At first glance, it might appear that the present study contradicts Graves' results, since rising air in the level of the secondary tropopause (300–150 mb.) could be expected to cause the tropopause to lift. However, as Miller [6] pointed out, two factors, vertical velocity and advection combine to change the height of the tropopause, and the signs of the vertical motion and the change in the height of the tropopause are not necessarily the same. Figure 3 shows a case in which strongly descending air at 200 mb. is superimposed on rising air at 300 mb. It is suggested that

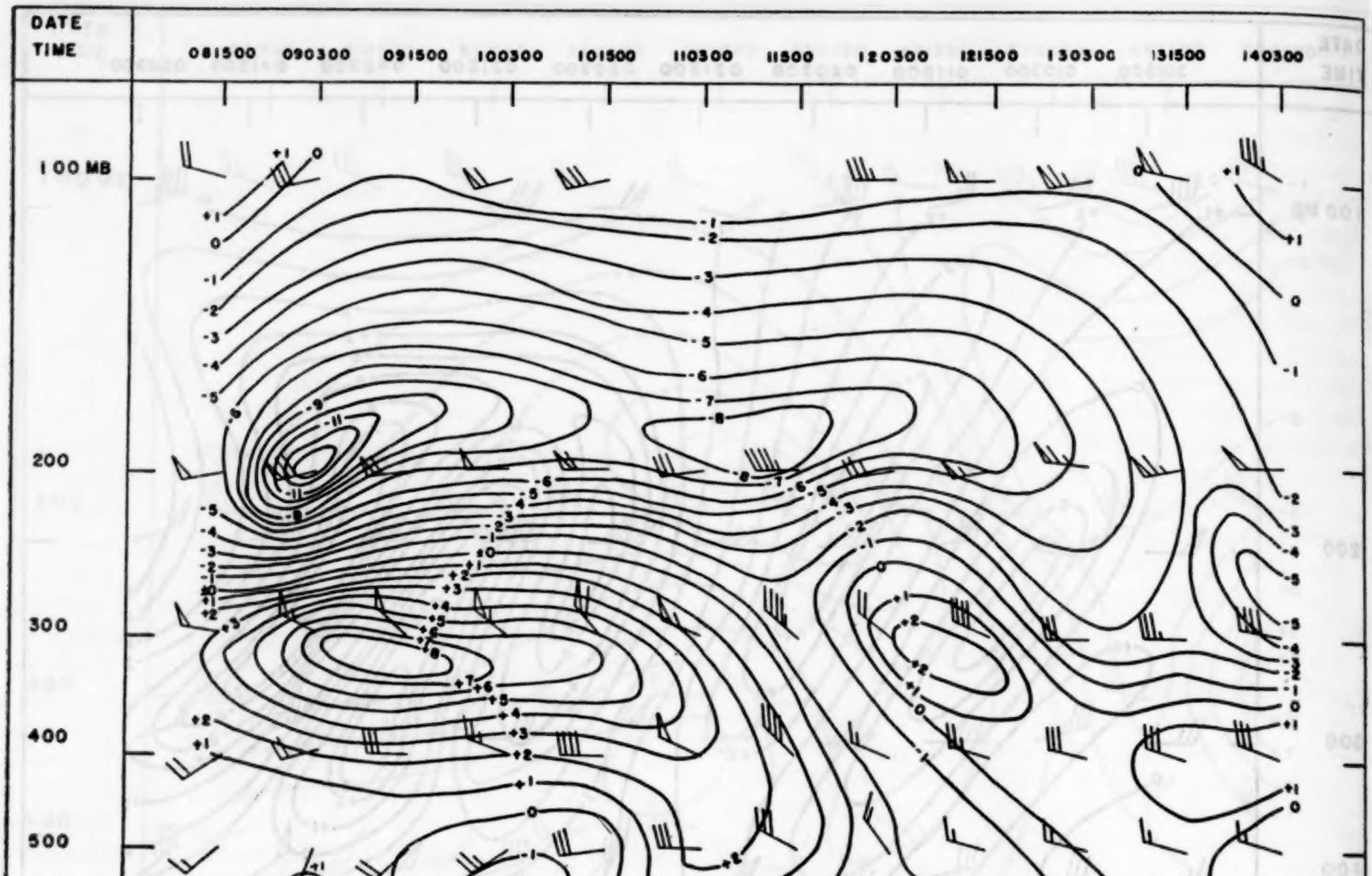


Figure 3.—Time cross section over San Juan, Puerto Rico, 1500 GMT February 8 to 0300 GMT February 14, 1952. Isopleths of vertical motion are indicated in cm. sec.$^{-1}$. Rainfall amounts are in inches and wind speeds in knots.

this is a possible mechanism for the production and maintenance of the secondary tropopause as observed by Graves, by steepening the lapse rate from below and stabilizing it from above. It seems logical that the break in the lapse rate thus produced (identified by Graves as a secondary tropopause) might be expected to lower whenever the center of maximum positive vertical velocity begins to migrate to a lower level, which as stated above was observed to occur just before precipitation began.

Finally, an effort was made to discover some element highly correlated with vertical motion at the latitude of Puerto Rico. Miller [6], for example, found a good correlation between the vertical motion in the temperate latitudes and the meridional flow, but this relationship did not appear to exist in the Tropics. Vertical motion computations as carried out by the method used in this investigation are very time consuming, and if some other element could be used instead, the value of vertical motion as a forecast tool would be increased.

Three linear correlations were computed, using the vertical motion at 200 mb. and (1) the 24-hour thickness change for the layer 300 to 200 mb., (2) the 24-hour temperature changes at 200 mb., and (3) the wind shear term for the 300- to 200-mb. layer. The value of the first was negligible, 0.05. In interpreting the other two correlation coefficients it should be remembered that both the 24-hour temperature change and the wind shear were used in computing the vertical motions with which they

are correlated. The only thing they reveal is the relative importance of the linear contribution of the two terms used in the computations. The correlation between vertical velocity and 24-hour temperature changes was −0.03, and that for vertical velocity and wind shear was −0.96. This shows that the wind shear term was the predominating factor in determining the sign and magnitude of the vertical motion. This was obvious throughout the course of the investigation. The use of wind shear alone would give values almost as good as the relationship actually used. However, this would not greatly simplify the method, since the 24-hour temperature changes are relatively simple to obtain. Also, it should be pointed out that the use of the wind shear term alone would probably not prove satisfactory in computing vertical velocity in temperate latitudes, due to stronger temperature gradients and the resulting greater temperature advection.

SUMMARY

The appearance of strong upward motion within the layer 400 to 100 mb. indicated that moderate to heavy rainfall was likely within 60 hours, the average time being 30 hours. The absence of such a period of rising air indicated that above normal rainfall was improbable. This is suggested as a possible forecast tool in tropical and subtropical latitudes. The equation of continuity requires that upward motion in the region of the upper troposphere be compensated by low level horizontal convergence, and it is probable that it is this convergence which causes the prolonged shower activity found to be associated with the periods of positive vertical motion in the higher levels. Figures 1–3 actually show in some cases this low level convergence and their failure to show it more definitely is probably due to shortcomings in the method used to compute the vertical motion. The presence of the upper level ascending motion could be detected in advance whenever associated with a disturbance approaching Puerto Rico from the west. These were polar troughs, shear lines, and the rare cold front which penetrated to this latitude. Such ascending motion could not be detected in the case of disturbances with deep easterly flow, viz easterly waves and related phenomena.

A mechanism for the production and maintenance of the secondary tropopause in the Tropics is suggested. It consists of the superimposition of a strongly divergent flow on a layer of air undergoing horizontal convergence, which steepens the lapse rate from below and stabilizes it from above. This process appears to be a frequent occurrence in the Tropics.

ACKNOWLEDGMENTS

The writer is particularly indebted to Mr. Glenn Stallard, who offered helpful criticisms and encouragement during the early phases of this investigation; to Mr. R. V. Gonzales, who assisted in the preparation of the charts; and to Messrs. C. W. Hostetter and R. S. Schrag, who read the manuscript and assisted in its revision.

REFERENCES

1. Gordon E. Dunn, "Tropical Cyclones," *Compendium of Meteorology*, American Meteorological Society, Boston 1951, pp. 887–901.
2. H. Riehl, "Waves in the Easterlies and the Polar Front in the Tropics," *Misc. Reports No. 17*, Department of Meteorology, University of Chicago, 1945, 79 pp.
3. C. E. Palmer, "Tropical Meteorology," *Compendium of Meteorology*, American Meteorological Society, Boston 1951, pp. 859–880.
4. H. A. Panofsky, "Methods of Computing Vertical Motion in the Atmosphere," *Journal of Meteorology*, vol. 3, No. 2, June 1946, pp. 45–49.
5. H. A. Panofsky, "The Effect of Vertical Motion on Local Temperature and Pressure Tendencies," *Bulletin of the American Meterological Society*, vol. 25, No. 7, September 1944, pp. 271–275.
6. James E. Miller, "Studies of Large Scale Vertical Motion of the Atmosphere," *Meteorological Papers*, vol. 1, No. 1, New York University, 1948, 49 pp.
7. H. A. Panofsky, "Large-Scale Vertical Velocity and Divergence," *Compendium of Meteorology*, American Meteorological Society, Boston 1951, pp. 639–646.
8. Maurice E. Graves, "The Relation Between the Tropopause and Convective Activity in the Subtropics (Puerto Rico)," *Bulletin of the American Meteorological Society*, vol. 32, No. 2, February 1951, pp. 54–60.

A NEW CONCEPT OF SKILL SCORE FOR RATING QUANTITATIVE FORECASTS

EDWARD M. VERNON

Weather Bureau Forecast Center, San Bruno Calif.

[Manuscript received November 8, 1951]

ABSTRACT

Skill scores for rating quantitative forecasts are proposed to take into account the deviations occurring between forecast and observed values. One score, the "deviation" skill score, weights the forecasts linearly according to the deviation; a second score, the "quadratic" skill score weights them according to the square of the deviation. These two scores are compared with the conventional skill score for two sets of forecasts, and for the same forecasts with bias introduced. It is concluded that use of either the deviation or the quadratic skill score is preferable to use of the conventional skill score in rating quantitative forecasts. Examples of the step-by-step computations of the two new scores are given.

THE DEVIATION SKILL SCORE

The skill score, as first proposed by Heidke [1] and used during recent years for certain forecast verification purposes, may be written

$$S=\frac{R-E}{T-E} \tag{1}$$

where S is the skill score, R the number of correct forecasts, T the total number of forecasts, and E the number of forecasts expected to be correct on some standard such as chance.

This method of computing a skill score places the same weight on each incorrect forecast regardless of the amount by which the observed condition deviates from the forecast. In other words, a deviation of say 10 class intervals has no more effect on the skill score than one of but 1 class interval. For some purposes it would be advantageous to have the skill score evaluate the actual amount by which forecast and observed conditions differ, i. e., take into account the magnitude of error. To accomplish this end, an analogous equation for skill score may be written

$$S_d=\frac{\sum d_e-\sum d_f}{\sum d_e} \tag{2}$$

where S_d is the skill score which considers magnitude of deviations, hereafter referred to as the "deviation skill score," Σd_f is the sum of deviations occurring between forecast and observed values, and Σd_e is the sum of deviations to be expected on some basis such as chance.

The value of Σd_f and Σd_e can best be expressed in terms of row, column, and cell totals in the typical contingency table, wherein the frequencies of forecast values are arrayed in columns and of observed values in rows, while a given cell is identified by the row and column to which it alone is common. When the standard of reference is chance, the summations become

$$\sum d_f=\sum(n_{rc}d_{rc}) \tag{3}$$

$$\sum d_e=\sum\left(\frac{n_rn_c}{T}\,d_{rc}\right) \tag{4}$$

where n_r is the number of cases falling in a given row; n_c is the number of cases falling in a given column; n_{rc} is the number of cases in the cell at the intersection of row r and column c; n_rn_c/T is the number which would have fallen by chance in the cell representing the intersection of row r and column c; d_{rc} is the deviation represented by that cell and is equal to the number of class intervals by which the cell is removed from the perfect hit cell for the same column.

When the standard of reference is climatological expectancy, according to one of the more common definitions of that standard, Σd_f remains as expressed in (3) while Σd_e becomes

$$\sum d_e=\sum\left(\frac{n_rn_{ce}}{T}\,d_{rc}\right) \tag{5}$$

where n_{ce} represents the climatological expectancy for the column, i. e., the number of times which climatological averages would lead one to expect the observed conditions to fall in the particular class interval represented by the column. The other symbols in (5) remain as previously defined in (4) and (1).

THE QUADRATIC SKILL SCORE

In the foregoing equations all deviations are weighted linearly, a deviation of one class interval scoring as one unit deviation, two class intervals as two unit deviations,

and so on. Where it is desired to have the penalty increase as the square of the deviation this is accomplished by substituting d_f^2 for d_f; d_e^2 for d_e; and d_{re}^2 for d_{re}. Hence, the quadratic deviation skill score* S_{d2}, in the computation of which the penalty increases as the square of the deviation of forecast from observed conditions, becomes

$$S_{d2}=\frac{\Sigma d_e^2-\Sigma d_f^2}{\Sigma d_e^2} \tag{6}$$

Where the standard of comparison is chance, Σd_f^2 and Σd_e^2 are given by

$$\Sigma d_f^2=\Sigma(n_{re} d_{re}^2) \tag{7}$$

and,

$$\Sigma d_e^2=\Sigma\left(\frac{n_r n_c}{T}\, d_{re}^2\right) \tag{8}$$

But if the standard of comparison is climatological expectancy, as previously defined in connection with equation (5), Σd_e^2 becomes:

$$\Sigma d_e^2=\Sigma\left(\frac{n_r n_{ce}}{T}\, d_{re}^2\right) \tag{9}$$

and Σd_f^2 remains as expressed in (7).

COMPARISON OF SKILL SCORES

Both the deviation skill score as computed by (2), and the quadratic skill score as computed by (6), conform to the usual conception of a skill score in that they vary on a scale of from zero to 1, with a value of zero indicating complete lack of skill over the standard of comparison, usually chance or climatological expectancy; and a value of 1 indicating the highest possible skill, with all observed data falling in the forecast class intervals. It is apparent that all three of these skill scores, S, S_d, and S_{d2} will be identical when the forecasts are either perfect or completely without skill. Just how they compare for the vast majority of forecasts which fall between these two extremes can be visualized to some extent by comparing scores attained on two sets of forecasts (A and B) presented in table 1.

In these two examples, based on hypothetical data, precipitation forecasts are made for the amount of rain which will fall. Rain is forecast and recorded in five class intervals as indicated in the column and row headings. The data for forecasts by A and for those by B have been arranged so that each forecaster scores the same number of direct hits, namely 80. This together with the fact that their row and column totals are identical causes both to attain the same skill score (0.36) as computed in the conventional way by equation (1). However, it is clear that if we attach any significance to the amount by which the forecast is missed, forecasts by B were superior to those by A. Forecaster B had 19 fewer large misses than did Forecaster A, i. e., misses of 2, 3, and 4 class intervals. He had a proportionately larger number of near misses, i. e., misses of but one class interval. Now, if we use equation

*Hereafter referred to as the quadratic skill score.

280852—54——2

TABLE 1.—*Contingency tables of precipitation forecasts by A and B, and corresponding S, S_d, and S_{d2}*

Forecasts by A

Observed	0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01	Total
0	65	5	2	1	1	74
0.01–0.20	9	6	3	3	1	22
0.21–0.50	4	5	4	2	1	16
0.51–1.00	1	2	3	3	1	10
≥1.01	1	1	2	2	2	8
Total	80	19	14	11	6	80 / 130

$S=0.362$
$S_d=.498$
$S_{d2}=.602$

Forecasts by B

Observed	0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01	Total
0	65	9				74
0.01–0.20	10	6	6			22
0.21–0.50	5	4	4	2	1	16
0.51–1.00			4	3	3	10
≥1.01				6	2	8
Total	80	19	14	11	6	80 / 130

$S=0.362$
$S_d=.639$
$S_{d2}=.824$

(2) and compute their deviation skill scores we find that B attains a higher value, scoring 0.64 against 0.50 for A. Furthermore, we note that if we square the deviations and compute quadratic skill scores by equation (6), the difference between the two sets of forecasts becomes even more pronounced, B scoring 0.82 against only 0.60 for A.

It would appear that for verifying quantitative forecasts, the deviation and quadratic skill scores, as herein defined, give better indications of the relative degree of skill than does the conventional skill score. However, before reaching such a conclusion we must consider the possibility that rating on the basis of the size of the deviations will lead forecasters to bias their forecasts by forecasting the middle class interval, where the largest possible deviation is at a minimum, rather than trying to catch extreme conditions by forecasting the extreme class intervals where the largest possible deviation is at a maximum.

To examine this possibility, the forecasts by A and B have been biased by placing all of the rain forecasts in the middle class interval as shown in table 2. In other words, every time A forecasts rain we have placed the forecast in

TABLE 2.—*Contingency tables of biased precipitation forecasts by A and B, and corresponding scores S, S_d, and S_{d2}*

Forecasts by A

Observed	0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01	Total
0	65		9			74
0.01–0.20	9		13			22
0.21–0.50	4		12			16
0.51–1.00	1		9			10
≥1.01	1		7			8
Total	80		50			77 / 130

$S=0.323$
$S_d=.469$
$S_{d2}=.582$

Forecasts by B

Observed	0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01	Total
0	65		9			74
0.01–0.20	10		12			22
0.21–0.50	5		11			16
0.51–1.00			10			10
≥1.01			8			8
Total	80		50			76 / 130

$S=0.310$
$S_d=.482$
$S_{d2}=.631$

TABLE 3.—*Computation of "deviation" skill score, S_d, for set of forecasts appearing in table 3A below*

TABLE 3A.—*Array of frequencies of forecast and observed values:*

n_r, n_c, and n_{rc}

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01	
0	65	5	2	1	1	74
0.01–0.20	9	6	3	3	1	22
0.21–0.50	4	5	4	2	1	16
0.51–1.00	1	2	3	3	1	10
≥1.01	1	1	2	2	2	8
Total	80	19	14	11	6	80 / 130

TABLE 3B.—*Array of deviation represented by each cell:*

d_{rc}

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	0	1	2	3	4
0.01–0.20	1	0	1	2	3
0.21–0.50	2	1	0	1	2
0.51–1.00	3	2	1	0	1
≥1.01	4	3	2	1	0

TABLE 3C.—*Array of number of cases expected by chance in each cell:*

$$\frac{n_r n_c}{T}$$

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	45.54	10.82	7.97	6.26	3.42
0.01–0.20	13.54	3.22	2.37	1.86	1.02
0.21–0.50	9.85	2.34	1.72	1.35	0.73
0.51–1.00	6.15	1.46	1.08	0.85	0.46
≥1.01	4.92	1.17	0.86	0.68	0.37

TABLE 3D.—*Array of chance frequencies weighted by cell deviation:*

$$\frac{n_r n_c}{T} d_{rc} = \text{(table 3B) (table 3C)}$$

$$\sum\left(\frac{n_r n_c}{T} d_{rc}\right) = \sum d_e = 155.26$$

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	0	10.82	15.94	18.78	13.68
0.01–0.20	13.54	0	2.37	3.72	3.06
0.21–0.50	19.70	2.34	0	1.35	1.46
0.51–1.00	18.45	2.92	1.08	0	0.46
≥1.01	19.68	3.51	1.72	0.68	0

TABLE 3E.—*Array of forecast frequencies weighted by cell deviation:*

$$n_{rc} d_{rc} = \text{(table 3A) (table 3B)}$$

$$\Sigma(n_{rc} d_{rc}) = \Sigma d_f = 78$$

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	0	5	4	3	4
0.01–0.20	9	0	3	6	3
0.21–0.50	8	5	0	2	2
0.51–1.00	3	4	3	0	1
≥1.01	4	3	4	2	0

$$S_d = \frac{\Sigma d_e - \Sigma d_f}{\Sigma d_e} = \frac{155.26 - 78}{155.26} = .498$$

TABLE 4.—*Computation of "quadratic" skill score, S_{d2}, for set of forecasts appearing in table 4A below*

TABLE 4A.—*Array of frequencies forecast and observed values:*

n_r, n_c, and n_{rc}

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01	
0	65	5	2	1	1	74
0.01–0.20	9	6	3	3	1	22
0.21–0.50	4	5	4	2	1	16
0.51–1.00	1	2	3	3	1	10
≥1.01	1	1	2	2	2	8
Total	80	19	14	11	6	80 / 130

TABLE 4B.—*Array of squared deviation represented by each cell:*

d^2_{rc}

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	0	1	4	9	16
0.01–0.20	1	0	1	4	9
0.21–0.50	4	1	0	1	4
0.51–1.00	9	4	1	0	1
≥1.01	16	9	4	1	0

TABLE 4C.—*Array of number of cases expected by chance in each cell:*

$$\frac{n_r n_c}{T}$$

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	45.54	10.82	7.97	6.26	3.42
0.01–0.20	13.54	3.22	2.37	1.86	1.02
0.21–0.50	9.85	2.34	1.72	1.35	0.73
0.51–1.00	6.15	1.46	1.08	0.85	0.46
≥1.01	4.92	1.17	0.86	0.68	0.37

TABLE 4D.—*Array of chance frequencies weighted by squared cell deviation:*

$$\frac{n_r n_c}{T} d^2_{rc} = \text{(table 4B) (table 4C)}$$

$$\sum\left(\frac{n_r n_c}{T} d^2_{rc}\right) = \sum d^2_e = 387.4$$

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	0	10.82	31.88	56.34	54.72
0.01–0.20	13.54	0	2.37	7.44	9.18
0.21–0.50	38.40	2.34	0	1.35	2.92
0.51–1.00	55.35	5.84	1.08	0	0.46
≥1.01	78.72	10.53	3.44	0.68	0

TABLE 4E.—*Array of forecast frequencies weighted by square of cell deviation:*

$$n_{rc} d^2_{rc} = \text{(table 4A) (table 4B)}$$

$$\Sigma(n_{rc} d^2_{rc}) = \Sigma d^2_f = 154$$

Observed	Forecast 0	0.01–0.20	0.21–0.50	0.51–1.00	≥1.01
0	0	5	8	9	16
0.01–0.20	9	0	3	12	9
0.21–0.50	16	5	0	2	4
0.51–1.00	9	8	3	0	1
≥1.01	16	9	8	2	0

$$S_{d2} = \frac{\Sigma d^2_e - \Sigma d^2_f}{\Sigma d^2_e} = \frac{387.4 - 154}{387.4} = .602$$

the column representing a forecast of 0.21 to 0.50 inch in which the largest possible deviation is two class intervals. Forecasts by B were biased in the same manner. The verification of forecasts by A and B, biased in this manner, is shown in table 2. By comparing these scores with those accompanying table 1 we can see what effect the bias produced on the scores.

It is readily apparent that even on the poorer forecasts, i. e., those by A, there was some loss in score caused by the introduction of bias. The conventional skill score S dropped from 0.36 to 0.32, a loss of 4 points. S_d and S_q dropped by smaller amounts, 3 and 2 points respectively. Thus it would at first appear that the conventional skill score places the greatest penalty on bias and is in that respect to be preferred over the deviation skill score and the quadratic skill scores presented in this article. However, before reaching such a conclusion let us see how the bias affected scores on the better set of forecasts, i. e. forecasts by B.

Here we see that while the conventional skill score S dropped 5 points because of the bias, the deviation skill score dropped 16 points and the quadratic skill score 19 points because of the same bias. Thus we see that for quantitative forecasts attaining a relatively high degree of skill in forecasting the correct class interval, the quadratic and deviation skill scores penalize unwarranted bias more than does the conventional skill score. However, on forecasts attaining a relatively low degree of skill the situation is reversed. This can be interpreted as an argument for use of either the deviation or the quadratic skill score in preference to the conventional skill score in rating quantitative forecasts, because their use would on the one hand appear to encourage forecasting the exact class interval where the verification expectancy is sufficiently high, and on the other hand would place a minimum penalty on biasing the forecast toward the middle class interval when the forecaster knows that his verification expectancy is low.

EXAMPLES OF COMPUTATIONS

To assist the reader in visualizing the application of the formulae, two sets of computations are shown in tables 3 A–E, and tables 4 A–E. These tables show how both the "deviation" and "quadratic" skill scores were computed for forecasts by A appearing in table 1.

REFERENCE

1. P. Heidke, "Berechnung des Erfolges und der Güte der Windstärkevorhersagen im Sturmwarnungsdienst," *Geografiska Annaler*, vol. 8, No. 4, 1926, pp. 310–349.

COMPUTING INSOLATION BY EMPIRICAL METHODS

J. NEUMANN

Israel Meteorological Service, Hakirya, Tel Aviv, Israel

[Manuscript received July 29, 1953; revision received November 4, 1953]

ABSTRACT

An empirical method described by Klein is applied to calculate insolation for the Lake Hefner, Okla., area for 1 year of the Lake Hefner Studies. For some of the months, the computed values show unsatisfactory agreement with the observed amounts, but the computed annual total is in close accord with the observed annual total.

It is suggested that agreement between the monthly values may be improved by introducing a curvilinear regression in the formula whereby account is taken of the depletion of insolation by sky coverage.

In connection with the recent Lake Hefner Studies, Anderson [1] has tested the usefulness of some empirical methods for the computation of insolation. He compares the results with the values determined by means of a pyrheliometer and finds that, *e. g.*, Mosby's formula

$$Q_s = k\ (1 - 0.071c)h, \qquad (1)$$

where Q_s is the amount of insolation on the horizontal in gcal. cm.$^{-2}$ min.$^{-1}$, k, a constant depending on geographical latitude, c, the average cloud cover in tenths of the sky covered, and h the average altitude of the sun in degrees, yields results which are too low if one retains Mosby's values of the constants. The insolation calculated for the period September 1, 1950, to August 31, 1951, is approximately 15 percent less than the observed amount.

As for a number of climatological applications it is desirable to have an indirect method which will give results of greater accuracy, we have tested the method described by Klein [2] for the Lake Hefner area for the period examined by Anderson. In this, monthly averages of the following basic meteorological and geophysical data were used, enumerated in the order as they appear in the calculations:

1. *Surface vapor pressure e:* The agencies cooperating in the Lake Hefner Studies have measured e over the lake itself but we have deliberately chosen the data of an ordinary meteorological station. Anderson has used in equation (1) the cloud cover data of the Weather Bureau station at Will Rogers Airport, which is situated about 20 km. south of the lake. As we also shall use the cloud cover data of the same station [3], the most consistent procedure would have been to take the vapor pressure data of the Airport. These, however, were not available in published form and, therefore, we have resorted to the vapor pressure data of the station at the Weather Bureau Office, Oklahoma City, Okla., the station being located some 13 km. southeast from the lake. The data in table 1 are the averages of the published 6-hourly observations [4].

2. *Precipitable water W in the atmosphere:* This was computed from a Hann-type empirical equation $W = \alpha e$, α being a suitable constant and e the surface vapor pressure. To reduce errors in these estimates, we have taken, as recommended by Klein ([2], p. 120), $\alpha = 2.5$ for winter (December through February), $\alpha = 2.1$ for summer (June through August); for spring and fall, the original Hann value of $\alpha = 2.3$ was applied. With these constants, e is in cm. Hg. and W in cm.

3. *Barometric pressure p:* This is required to correct for station level the values of mean solar air mass published for sea level pressures. The pressure values in table 1 are those of Will Rogers Airport [3], increased by 3 mb. to correct for difference in elevation (the elevation of the airport is about 27 m. greater than that of the lake surface). This correction is purely nominal as it does not affect the first decimal of the figures representing mean solar air mass. There is no point in computing the mean solar air mass beyond the first decimal.

4. *Mean solar air mass m*: Obtained by interpolation from a table by Kennedy [5] and then corrected for station-level pressure.

5. *Fraction d of insolation depleted by atmospheric dust*: It will be assumed that $d = 0$. This assumption will be reconsidered below.

6. *Daily amount of solar radiation I_0 reaching the top of the atmosphere*: This quantity can be computed from a theoretical formula (e. g., Humphreys, [6], p. 88). It is also available in tables, as for instance in Kennedy's [5] paper.

7. *Cloud cover c*: Data of Will Rogers Airport [3]. As mentioned above, the cloud cover data of this station were used by Anderson in connection with Mosby's equation.

With the help of the data 1 to 5 inclusive, one can compute the transmission coefficient of insolation $(a + \frac{1}{2}s)$ where a is the transmission coefficient of insolation for a cloudless sky and s the fraction representing total depletion by atmospheric scattering and diffuse reflection, dust absorption having been assumed to be negligible. The

factor ½ of s in the coefficient above is connected with the assumption, due to Kimball (Klein, [2], p. 122), that about half of the incoming radiation scattered and diffusely reflected by the atmosphere is received at the ground as diffuse radiation from the sky. The daily amount of insolation Q_c on the horizontal reaching the surface from a cloudless sky is obtained from the formula

$$Q_c = I_0\,(a+\tfrac{1}{2}\,s) \tag{2}$$

while the depletion of insolation by a cloud cover of c tenths is approximated with the aid of the formula

$$Q_s = Q_c\,(1-0.071\,c). \tag{3}$$

It is seen from table 1 that the computed monthly values of daily insolation diverge, in some cases considerably, from the observed values. Particularly poor is the result for August 1951. The yearly averages, however, are in rather good agreement, the computed value being about 1 percent higher than the observed value. Had we considered the estimated effect of depletion by dust and introduced such values of d as mentioned *e. g.* by Klein, the resulting annual average would have come out 1 or 2 percent lower than the observed average, so that the result would have hardly been less good.

It is of course very probable that the good agreement between the annual figures is partly fortuitous. But it is worth noting in table 1 that the signs of deviations of the monthly figures are not as uniform as in the case examined by Anderson, a fact which is conducive to producing the agreement in the annual figures.

The method of computation does not take account of the type and thickness of clouds, nor the height above surface of the cloud cover. Indeed, it would be rather difficult to consider these factors as they are seldom observed in a reliable manner. However, the table does suggest that the agreement between the computed and the observed monthly values might be improved by the use of a curvilinear regression in lieu of the straight-line regression $(1-0.071\,c)$ whereby allowance is made for the depletion of insolation by the amount of cloud. It is seen from the table that, for this small sample at least, the straight-line regression tends to underestimate insolation at the greater cloud amounts and overestimate it at the lesser cloud amounts.

TABLE 1.—*Computation of insolation on the horizontal with the aid of method described by Klein [2] and comparison of results with observed amounts for the Lake Hefner, Okla., area: September 1950 to August 1951*

[Symbols defined and sources of data [3, 4] stated in the text]

Month	e	W	p	m	$(a+\frac{1}{2}s)$	I_0	Q_c	c	Q_s		Percent error
	cm. Hg.	cm.	mb.			$\frac{\text{gcal}}{\text{cm.}^2\text{ day}}$	$\frac{\text{gcal}}{\text{cm.}^2\text{ day}}$	tenths	$\frac{\text{gcal}}{\text{cm.}^2\text{ day}}$		
									comp.	obs.	
1950											
Sept	1.41	3.2	972	2.9	0.89	805	716	5.8	422	417	+1
Oct	.98	2.3	973	3.3	.89	598	532	3.0	420	390	+8
Nov	.39	.9	975	3.7	.91	460	419	3.8	306	287	+7
Dec	.31	.8	974	4.2	.90	392	353	3.8	258	233	+11
1951											
Jan	.30	.7	974	3.9	.92	428	394	4.8	260	275	−5
Feb	.43	1.1	974	3.5	.91	547	498	6.0	284	322	−12
Mar	.40	.9	971	3.1	.92	701	645	5.2	406	424	−4
Apr	.61	1.4	969	2.8	.92	847	779	5.0	506	516	−2
May	1.12	2.6	971	2.7	.90	946	851	5.3	528	541	−3
June	1.63	3.4	969	2.7	.90	981	883	5.6	530	591	−10
July	1.84	3.9	971	2.7	.89	959	854	3.7	632	611	+3
Aug	1.65	3.5	971	2.8	.90	946	851	2.8	681	576	+18
							Average*		437	433	

*Obtained from monthly values weighted for length of month.

ACKNOWLEDGMENT

The writer is indebted to Mr. W. E. Maughan, Meteorologist in Charge, Oklahoma City Office, U. S. Weather Bureau, for the data of the stations at Oklahoma City and at Will Rogers Airport.

REFERENCES

1. E. R. Anderson, "Energy-Budget Studies," in "Water-Loss Investigations: Volume 1—Lake Hefner Studies Technical Report," *Geological Survey Circular* 229, Washington, 1952, pp. 71–119.
2. W. H. Klein, "Calculation of Solar Radiation and the Solar Heat Load on Man," *Journal of Meteorology*, vol. 5, No. 4, August 1948, pp. 119–129.
3. U. S. Weather Bureau, *Station Meteorological Summary* for Will Rogers Field, Okla., 1950–51.
4. U. S. Weather Bureau, *Special Meteorological Summary* for Oklahoma City, Okla., 1950–51.
5. R. E. Kennedy, "Computation of Daily Insolation Energy," *Bulletin of the American Meteorological Society*, vol. 30, No. 6, June 1949, pp. 208–213.
6. W. J. Humphreys, *Physics of the Air*, 3d Edition, McGraw-Hill, New York, 1940, 676 pp.

COMPARATIVE LOCAL NOON TEMPERATURE AND HUMIDITY DATA FOR THE UNITED STATES

W. P. DAY

U. S. Weather Bureau Forecast Center, Washington National Airport, Washington, D. C.

[Manuscript received June 30, 1953; revised November 2, 1953]

There is frequent inquiry for comparative temperature and humidity data in the United States. However, most of the available humidity data are for the synoptic hours 0630 GMT, 1230 GMT, etc., which because of the differences in local time are not comparable. Between Eastport, Maine, and Tatoosh Island, Wash., there is a difference of nearly four hours in local time so that the diurnal curve of humidity is out of phase when comparing synoptic observations from places in the Atlantic States with those near the Pacific coast. To avoid this difficulty observations were made by the Weather Bureau at noon local time at all first-order stations from 1918 to 1938 inclusive, a period of 21 years. Since these observations were made at approximately the time when the sun was on the meridian, they should be strictly comparable over the entire country.

Average values for the 21-year period for the months of January, April, July, and October for the stations included in the survey were computed and are shown in table 1. For January and July, points for the various stations were plotted on linear graph paper as a function of the mean temperature and humidity values; these charts are shown as figures 1 and 2. The chart for July is naturally the most interesting. Widely separated are the warm and humid stations on the Gulf and South Atlantic coasts and the very cool and humid North Pacific coast stations. Eureka, Calif., in the low temperature and high humidity part of the diagram, is contrasted with Red Bluff, Calif., about 100 miles distant across the Coastal Ranges but located up in the dry and warmer portion of the chart.

It should be noted that the daily values at the various stations vary over a wide range and that human comfort is a function not only of temperature and humidity but also of other weather factors such as wind and sunshine. There are also other ways in which the humidity data may be expressed, given the temperature and relative humidity data, but such conversions, if needed for special purposes, are left to the reader.

TABLE 1.—*Mean local noon temperature and humidity, 21-yr. period 1918–38 incl.*

	January		April		July		October		Years record (21 unless otherwise indicated)
	T (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	
ALABAMA									
Birmingham	50.4	60	69.0	50	86.3	57	73.5	50	------
Mobile	56.8	67	71.8	60	86.3	63	76.0	58	------
Montgomery	53.3	62	70.3	53	86.5	58	73.9	51	------
ALASKA									
Juneau	30.0	75	43.8	62	59.4	73	45.6	78	------
ARIZONA									
Phoenix	59.8	33	78.1	21	98.6	28	82.7	25	------
Yuma	64.3	29	81.8	20	101.3	28	85.5	26	------
ARKANSAS									
Fort Smith	43.0	65	66.8	54	88.7	52	70.3	54	------
Little Rock	44.6	64	66.9	52	87.2	53	70.3	53	------
CALIFORNIA									
Eureka	50.8	77	53.5	76	57.6	80	57.4	77	------
Fresno	49.5	70	68.2	41	90.7	23	73.0	39	------
Independence	48.5	32	65.8	24	90.6	15	68.7	22	7
Los Angeles	62.6	44	66.7	52	77.8	54	73.5	47	------
Red Bluff*	47.5	68	65.6	46	90.1	26	71.0	41	*20
Sacramento	47.0	80	63.9	56	81.9	40	68.8	49	------
San Diego	61.1	55	63.1	66	70.8	72	68.5	65	------
San Francisco	51.5	69	60.7	60	63.4	68	65.9	58	------
San Jose	53.5	64	65.0	50	76.5	48	68.9	50	15
San Luis Obispo	61.0	42	64.0	54	73.3	48	72.7	41	9
COLORADO									
Denver	37.8	42	53.5	39	81.3	32	59.5	37	------
Grand Junction	30.6	59	59.0	31	85.7	28	62.2	34	------
Pueblo	39.8	43	58.7	32	85.4	30	63.7	33	------

*Red Bluff 16 years plus Redding 4 years.

TABLE 1.—*Mean local noon temperature and humidity, 21-yr. period 1918–38 incl.*—Continued

	January		April		July		October		Years record (21 unless otherwise indicated)
	T (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	
CONNECTICUT									
New Haven	32.3	64	51.7	58	77.3	61	60.0	58	------
DISTRICT OF COLUMBIA									
Washington	37.9	58	58.3	48	82.3	54	63.7	53	------
FLORIDA									
Apalachicola	58.9	71	71.4	65	84.9	69	75.4	63	12
Jacksonville	60.8	64	73.5	57	85.6	61	76.2	62	------
Key West	73.5	72	79.9	66	86.3	68	82.3	71	------
Miami	72.7	65	78.1	63	84.9	68	81.2	68	------
Pensacola	56.4	73	69.1	70	83.2	71	74.4	65	------
Tampa	67.6	62	77.7	53	86.2	62	81.0	58	------
GEORGIA									
Atlanta	47.6	67	65.8	54	83.8	57	69.1	55	------
Augusta	52.8	63	70.6	52	87.2	57	73.7	52	------
Macon	52.9	59	70.2	47	86.1	56	73.2	50	------
Savannah	57.6	63	72.4	55	86.6	62	74.8	59	------
HAWAII									
Honolulu	74.8	65	75.8	63	80.4	61	80.5	64	------
IDAHO									
Boise	32.9	67	56.5	40	84.1	25	60.3	41	------
Pocatello	27.5	71	51.4	44	82.5	26	56.2	44	------
ILLINOIS									
Cairo	38.6	68	62.0	56	85.1	55	66.5	55	------
Chicago	27.6	70	50.4	61	78.1	59	59.1	58	------
Peoria	28.7	73	56.2	56	84.2	52	62.3	56	------
Springfield	30.7	72	57.9	56	85.3	49	63.0	55	------

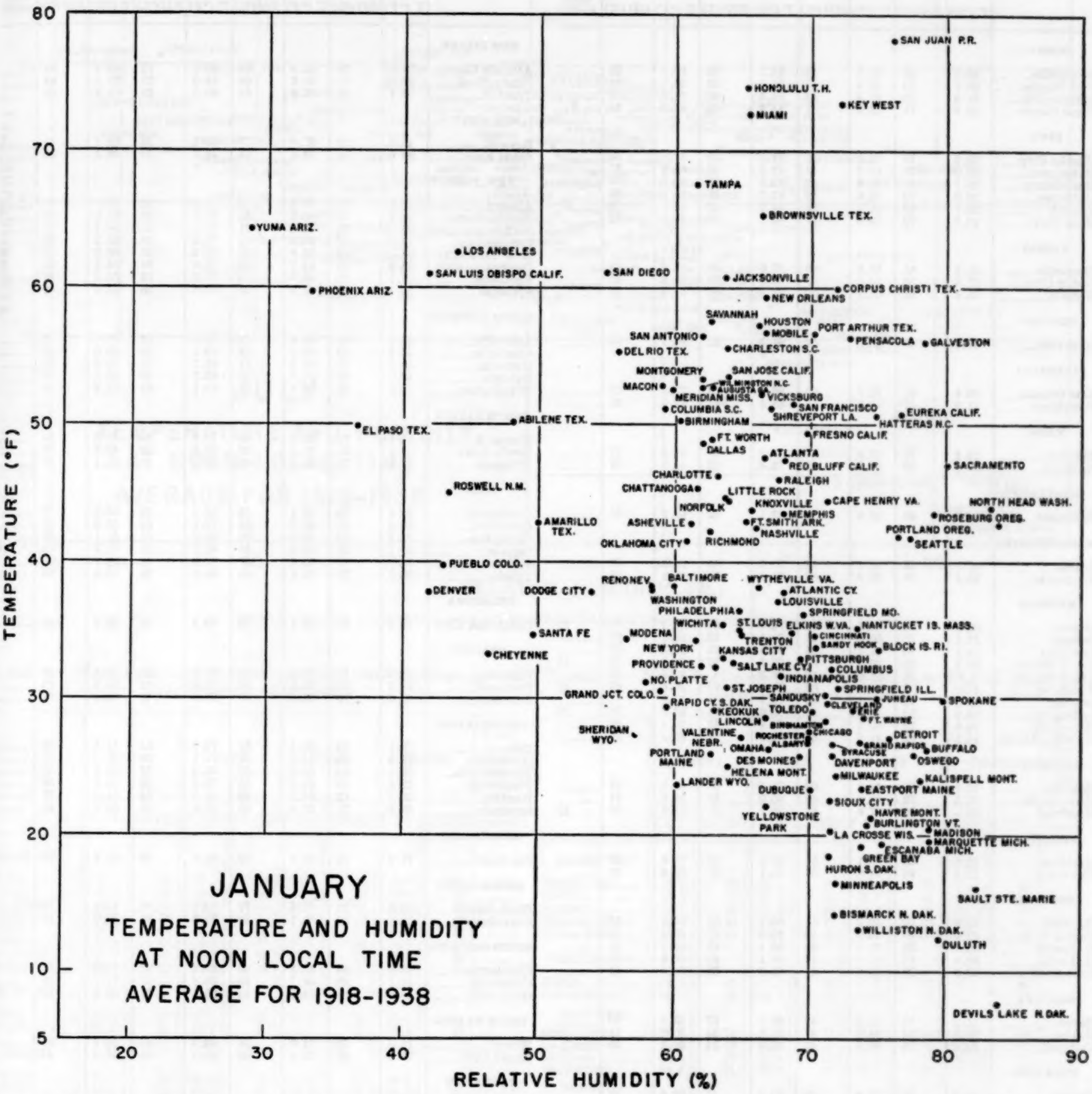


FIGURE 1.—Average values of local noon temperature and relative humidity for the month of January for various cities in the United States and possessions.

TABLE 1.—*Mean local noon temperature and humidity, 21-yr. period 1918–38 incl.*—Continued

	January		April		July		October		Years record (21 unless otherwise indicated)
	T (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	
INDIANA									
Evansville	36.9	68	61.0	52	85.7	50	66.1	52	------
Fort Wayne	28.7	74	52.8	57	81.0	50	59.4	58	------
Indianapolis	31.6	68	55.9	53	82.5	48	61.8	53	------
Terre Haute	32.3	71	57.8	57	84.4	49	63.2	54	------
IOWA									
Charles City	20.2	75	52.2	52	81.6	50	57.0	56	------
Davenport	25.9	72	54.6	55	82.9	50	60.0	57	------
Des Moines	25.7	69	55.4	52	83.8	49	60.6	53	------
Dubuque	23.3	70	52.6	52	81.0	51	58.1	56	------
Keokuk	29.1	63	56.4	53	84.2	49	62.1	53	------
Sioux City	22.5	72	53.9	51	83.2	49	58.4	52	------
KANSAS									
Concordia	31.2	65	58.8	49	87.0	44	63.6	48	------
Dodge City	37.8	54	60.8	45	88.5	39	65.8	45	------
Wichita	35.4	64	61.1	50	87.3	46	65.3	51	------
KENTUCKY									
Louisville	37.1	68	60.3	54	84.1	52	65.1	55	------
LOUISIANA									
New Orleans	59.4	67	73.7	60	86.4	63	77.5	59	------
Shreveport	51.2	67	70.8	55	88.1	55	74.6	54	------
MAINE									
Eastport	23.4	74	42.0	71	64.2	77	51.3	71	------
Portland	25.9	63	46.9	57	72.3	63	55.0	61	------
MARYLAND									
Baltimore	38.2	60	57.9	52	83.1	52	64.3	58	------
MASSACHUSETTS									
Boston	32.3	63	51.1	57	76.6	60	59.5	58	------
Nantucket	35.1	74	48.0	69	72.1	75	58.9	68	------
MICHIGAN									
Alpena	23.2	74	42.5	61	73.0	60	52.4	65	19
Detroit	27.1	76	50.0	61	79.1	52	57.5	61	------
Escanaba	19.1	75	41.1	63	70.9	65	50.3	67	------
Grand Haven	25.5	80	46.2	64	72.5	64	55.2	67	15
Grand Rapids	26.8	74	51.0	53	80.3	47	57.5	58	------
Houghton	17.0	79	41.9	61	70.4	64	49.6	69	15
Lansing	26.6	78	51.1	58	79.9	53	57.8	61	------
Ludington	23.9	82	43.9	69	69.0	71	53.0	70	15
Marquette	19.6	79	40.4	67	68.9	67	50.4	68	------
Sault Ste. Marie	16.1	82	41.6	62	71.5	61	49.4	70	------
MINNESOTA									
Duluth	12.4	80	41.7	62	71.4	64	49.0	67	------
Minneapolis	16.5	72	49.8	49	80.0	48	54.6	54	------
Moorhead	10.0	79	47.6	54	78.7	49	51.5	56	18
MISSISSIPPI									
Meridian	52.6	60	70.1	51	86.6	55	73.6	52	------
Vicksburg	52.2	66	69.8	57	86.1	61	73.6	56	------
MISSOURI									
Columbia	32.9	68	59.7	54	86.1	51	64.1	55	------
Kansas City	32.9	64	59.0	53	86.2	48	65.1	52	------
St. Joseph	30.9	64	58.8	50	86.1	48	63.7	51	------
St. Louis	34.9	65	60.0	55	86.1	49	64.8	53	------
Springfield	36.2	70	59.8	54	83.3	53	64.6	53	------
MONTANA									
Havre	21.2	75	51.0	47	80.0	37	53.5	50	------
Helena	25.0	64	48.2	47	77.1	35	50.2	51	------
Kalispell	24.0	78	49.5	47	75.9	34	50.3	56	------
NEBRASKA									
Lincoln	28.6	67	57.8	49	86.7	45	62.6	49	------
North Platte	31.2	58	56.1	45	85.1	43	61.7	42	------
Omaha	26.3	67	56.3	51	84.8	49	60.9	51	------
Valentine	27.2	65	52.7	48	83.4	41	58.6	44	------
NEVADA									
Reno	38.2	58	57.1	33	84.8	19	62.5	33	------
Winnemucca	34.6	63	56.7	36	86.8	18	62.4	33	------
NEW HAMPSHIRE									
Concord	25.2	70	50.7	61	76.8	62	57.0	65	16

TABLE 1.—*Mean local noon temperature and humidity, 21-yr. period 1918–38 incl.*—Continued

	January		April		July		October		Years record (21 unless otherwise indicated)
	T (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	
NEW JERSEY									
Atlantic City	37.8	68	51.9	65	76.0	72	62.3	64	------
Sandy Hook	33.7	70	51.6	63	78.0	65	60.2	64	------
Trenton	34.7	65	55.1	56	80.5	56	61.9	56	------
NEW MEXICO									
Roswell	45.0	43	67.6	27	86.1	36	68.7	41	------
Santa Fe	34.6	50	53.5	34	76.7	36	58.3	38	------
NEW YORK									
Albany	26.8	70	51.0	55	78.3	55	57.1	60	------
Binghamton	28.4	71	50.8	58	77.9	58	57.2	60	------
Buffalo	26.3	79	44.1	71	72.4	68	54.4	71	------
Canton	19.9	77	46.3	63	75.3	58	53.2	65	------
New York City	34.3	62	52.8	54	78.4	59	60.0	57	20
Oswego	25.8	78	44.7	66	72.9	64	54.8	65	20
Rochester	27.1	70	48.2	56	77.0	53	56.2	59	------
Syracuse	26.7	72	48.5	58	76.8	56	55.9	61	------
NORTH CAROLINA									
Asheville	42.9	61	60.9	49	79.8	56	64.4	52	------
Charlotte	46.2	63	65.0	53	84.6	55	68.8	51	------
Hatteras	50.6	75	63.2	71	81.7	74	70.3	71	------
Raleigh	46.0	68	64.5	58	83.7	59	68.3	55	------
Wilmington	52.8	62	68.4	56	84.1	64	71.9	55	------
NORTH DAKOTA									
Bismarck	14.1	72	49.8	48	79.8	45	53.3	50	------
Devils Lake	7.6	84	45.4	56	76.8	50	49.5	57	------
Williston	13.1	74	48.1	49	78.4	43	51.1	52	------
OHIO									
Cincinnati	34.6	70	58.1	53	83.4	52	63.8	53	------
Cleveland	29.6	71	48.2	64	75.1	62	58.0	60	------
Columbus	32.1	72	54.9	59	81.3	51	61.1	58	------
Dayton	31.5	71	56.0	55	81.7	50	61.7	55	18
Sandusky	30.2	71	50.8	61	79.6	56	59.7	59	------
Toledo	29.0	70	51.1	58	80.0	51	58.8	58	------
OKLAHOMA									
Oklahoma City	41.5	61	66.1	49	89.6	46	69.5	53	------
OREGON									
Baker	29.0	72	52.2	45	77.7	30	56.4	46	------
Portland	41.9	77	56.8	57	71.6	52	59.4	66	------
Roseburg	43.5	79	58.0	55	75.3	43	60.1	63	------
PENNSYLVANIA									
Erie	29.1	73	47.4	67	75.9	64	57.4	66	------
Harrisburg	32.6	63	54.2	51	79.9	53	60.0	55	------
Philadelphia	36.4	65	56.5	56	81.4	57	62.8	56	------
Pittsburgh	32.9	69	54.2	56	79.6	53	59.9	58	------
Reading	33.5	67	54.9	52	80.5	54	61.0	57	------
Scranton	29.9	71	52.4	59	78.8	55	58.2	62	------
PUERTO RICO									
San Juan	78.2	76	79.6	75	82.5	78	83.2	77	------
RHODE ISLAND									
Block Island	33.6	75	47.4	77	72.1	79	57.6	72	------
Providence	32.4	62	52.1	50	77.8	58	59.9	55	------
SOUTH CAROLINA									
Charleston	55.6	64	70.1	60	85.4	67	73.9	61	------
Columbia	51.1	59	68.7	50	85.9	57	71.9	51	------
Greenville	46.0	64	64.8	54	83.5	57	68.3	55	16
SOUTH DAKOTA									
Huron	18.5	72	51.9	51	82.4	46	56.7	48	------
Rapid City	29.4	60	50.3	50	80.4	43	57.0	44	------
TENNESSEE									
Chattanooga	45.4	62	65.4	50	84.7	55	68.6	52	------
Knoxville	43.8	66	64.3	51	84.0	55	67.6	52	------
Memphis	43.7	68	64.9	56	85.1	59	69.3	57	------
Nashville	42.5	66	64.2	50	85.3	53	68.2	52	------
TEXAS									
Abilene	50.2	48	72.5	38	90.6	40	74.3	46	------
Amarillo	42.9	50	63.8	40	86.0	40	67.0	46	------
Brownsville	65.4	66	78.5	60	87.7	59	81.7	59	16
Corpus Christi	60.0	72	74.5	69	86.8	66	79.6	65	------
Dallas	48.7	62	69.9	51	89.0	49	73.5	52	------

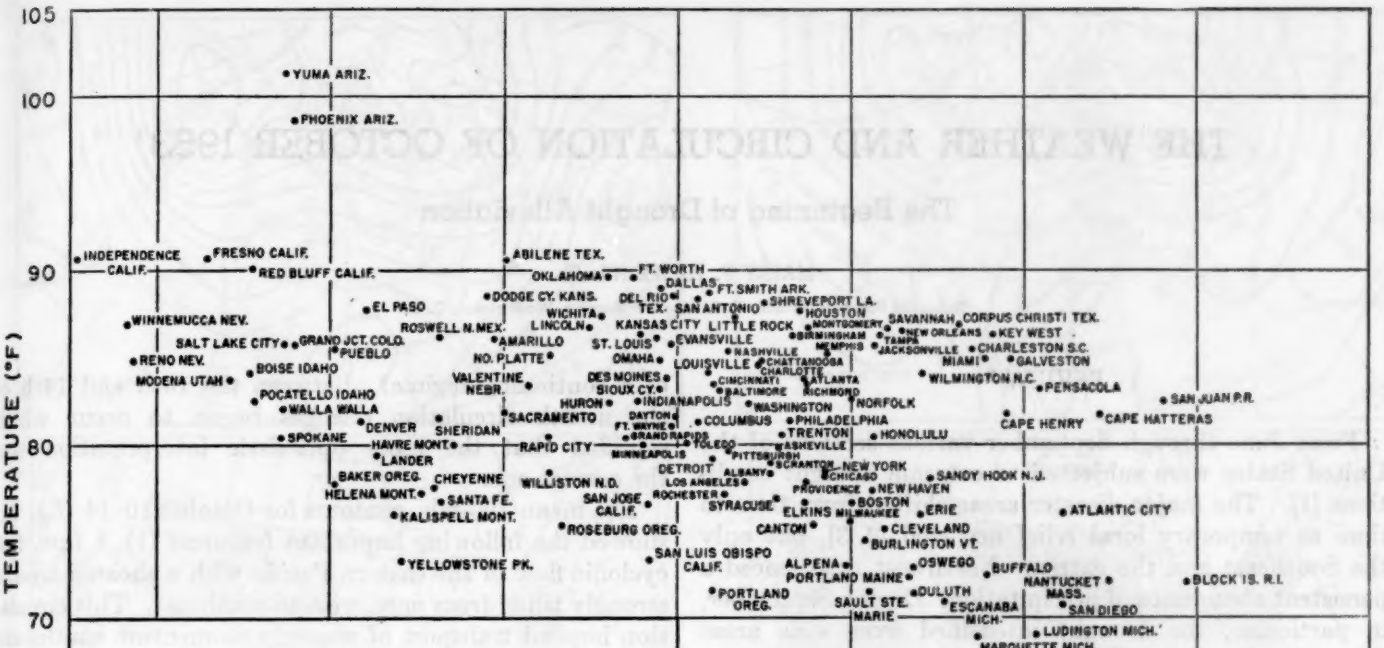


FIGURE 2.—Average values of local noon temperature and relative humidity for the month of July.

TABLE 1.—*Mean local noon temperature and humidity, 21-yr. period 1918–38 incl.*—Continued

	January		April		July		October		Years record (21 unless otherwise indicated)
	T (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	
TEXAS—con.									
Del Rio	55.3	56	75.3	46	88.5	50	76.5	54	------
El Paso	49.9	37	70.3	20	87.7	32	72.6	35	------
Fort Worth	49.0	63	70.1	53	89.6	48	73.9	53	------
Galveston	56.1	78	70.6	73	84.9	69	76.3	68	------
Houston	57.3	66	73.6	59	87.6	57	77.8	55	------
Palestine	51.9	65	70.6	57	87.7	54	74.9	53	------
Port Arthur	56.7	70	72.7	63	86.6	63	77.1	59	------
San Antonio	56.5	62	73.9	54	88.3	51	77.5	53	------
UTAH									
Modena	34.4	57	56.6	30	83.7	24	61.1	31	------
Salt Lake City	32.7	64	55.1	41	85.7	27	60.4	39	------
VERMONT									
Burlington	20.7	74	46.0	58	74.5	61	52.7	63	------
Northfield	19.4	71	46.1	57	74.7	60	53.0	62	17
VIRGINIA									
Cape Henry	44.5	71	59.1	66	81.8	69	66.9	65	------
Lynchburg	41.0	60	60.9	51	82.6	55	65.1	53	17
Norfolk	44.6	64	61.4	52	82.6	60	67.0	57	------
Richmond	42.3	63	62.0	54	83.7	57	67.1	53	------
Wytheville	38.2	66	57.0	54	77.8	58	62.0	55	------

TABLE 1.—*Mean local noon temperature and humidity, 21-yr. period 1918–38 incl.*—Continued

	January		April		July		October		Years record (21 unless otherwise indicated)
	T (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	*T* (°F)	*RH* (%)	
WASHINGTON									
North Head	43.9	83	50.1	79	58.4	85	55.3	84	------
Seattle	41.8	77	52.6	61	65.5	61	55.2	75	------
Spokane	29.9	80	54.8	43	80.4	27	55.3	54	------
Tatoosh Island	42.8	84	48.9	81	56.2	89	52.8	87	------
Walla Walla	34.7	73	58.1	43	82.1	27	59.8	50	------
WEST VIRGINIA									
Elkins	34.8	69	54.7	52	76.7	57	59.7	55	------
Parkersburg	36.2	67	58.6	50	81.9	53	63.1	55	------
WISCONSIN									
Green Bay	19.2	74	46.3	57	76.6	55	53.5	61	------
La Crosse	20.2	72	52.0	52	80.9	54	56.8	57	------
Madison	20.4	79	48.4	58	77.7	57	55.0	62	------
Milwaukee	24.4	72	46.6	65	75.5	60	55.7	63	------
WYOMING									
Cheyenne	33.2	46	47.4	47	77.4	36	54.6	43	------
Lander	23.6	60	48.1	48	79.3	33	53.1	44	------
Sheridan	27.4	57	51.2	44	81.5	36	56.0	43	------
Yellowstone Park	22.1	67	42.8	50	73.2	34	47.7	50	19

THE WEATHER AND CIRCULATION OF OCTOBER 1953[1]

The Beginning of Drought Alleviation

HARRY F. HAWKINS, JR.

Extended Forecast Section, U. S. Weather Bureau, Washington, D. C.

REVIEW[2]

From June through September various sections of the United States were subjected to extreme drought conditions [1]. The major disaster areas shifted from time to time as temporary local relief occurred [2, 3], but only the Southeast and the extreme Northwest experienced a persistent abundance of precipitation. During September, in particular, the drought intensified over wide areas from Arizona to New England. By the end of September it was evident that a repetition of last October's (1952) weather—the driest month on record in the United States [4]—would result in a most serious situation.

DROUGHT ALLEVIATION

This year, however, even early October gave evidence of some relief. During the first week a polar trough traversed the country spreading precipitation in a band from Texas to Michigan. Additional precipitation occurred as the cold air behind the associated front arrived over the Northeast and was effectively overrun by warm, moist air from a disturbance of tropical origin off the coast. In this manner temporary relief from extreme drought conditions was afforded appreciable sections of the critically dry area.

Following this promising interlude there was a return to the previous dry regime. Except for the extreme Southeast, Northeast, and Northwest, little precipitation of note occurred. The upper level ridge rebuilt over western North America and trough activity prevailed just off the east coast. This typical drought-producing circulation was accompanied by the frequently noted temperature pattern of warm in the West, cold in the East. The characteristics of such circulation and temperature patterns were recently described by Klein [1].

This reestablishment of the drought regime posed a question which commonly confronts prognosticators—Was the temporary break of early October a forerunner or precursory sign of a gradual relaxation of the prevailing (drought) pattern or merely an incidental interruption of a continuing regime? Between the 10th and 14th of the month circulation changes began to occur which signified that the more optimistic interpretation was the correct one.

The mean 700-mb. contours for October 10–14 (fig. 1a) showed the following important features: (1) A fast, flat cyclonic flow in the eastern Pacific with a sheared trough strongly tilted from northwest to southeast. This circulation implied transport of westerly momentum southward into the southwestern United States [5]. Usually the transition is accompanied by advection of cool maritime air, frontal and possibly cyclonic activity, and precipitation. (2) The ridge formerly over western North America had begun to move eastward particularly at lower latitudes. In this instance the ridge was located over Oklahoma—an area well recognized as unfavorable for prolonged anticyclonic circulation (except in summer) since it lies in the lee of the Continental Divide. Fairly rapid eastward translation of ridges located in this area usually occurs. (3) The east coast trough had made eastward motion and the mid-latitude (45° N.) wavelength was becoming very long.

The concomitant temperature anomaly (fig. 1b) reflected these changes. Cool maritime air had begun to penetrate the Far West as the center of warm air shifted eastward with the ridge, and the below normal areas of the East were confined almost exclusively to the area east of the Appalachians. The precipitation map (fig. 1c), showed continuation of the prevailingly dry regime. The upper level High over southern Texas prevented any sizable quantities of Gulf moisture from invading the United States. Precipitation had already spread down to central California, and by the end of the period some precipitation had been released as far east as the Panhandle.

Figure 2 depicts the mean state for the 5-day period 1 week later, October 17–21. The shear in the Pacific trough was now complete and the southern trough segment had entered the western United States.[3] It was now an independent trough in the long wave pattern and provided the necessary relaxation (at middle and lower latitudes) between the widely spaced mid-Pacific and western Atlantic troughs. The North American ridge,

[1] See Charts I–XV following p. 347 for analyzed climatological data for the month.

[2] Detailed statistics on this year's drought and comparison with previous great droughts are contained in a special issue of the *Weekly Weather and Crop Bulletin*, vol. XL, No. 45, November 6, 1953.

[3] A detailed investigation of some upper level aspects of this transition is described in an adjacent article by C. L. Kibler and E. F. Robinson.

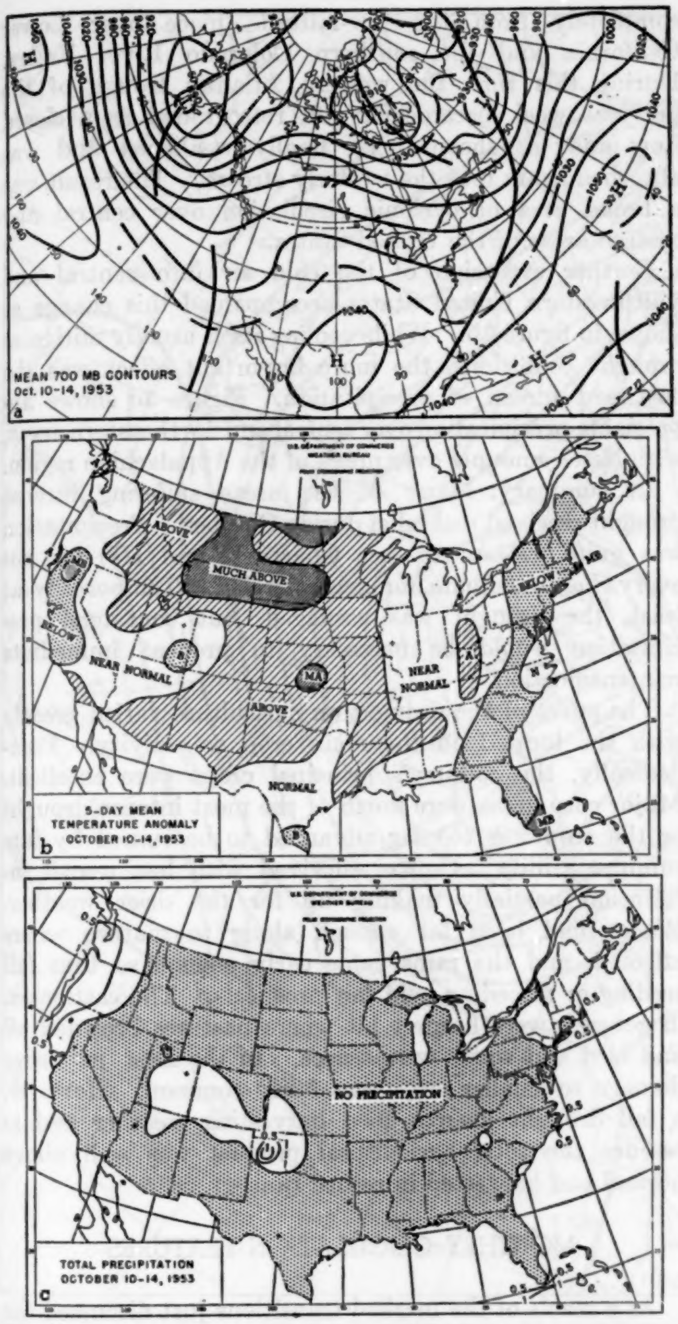


Figure 1.—Five-day means for October 10-14, 1953. a. 700-mb. heights in tens of feet. In the Pacific a tilted trough (actually sheared) with strong west-northwesterlies to its rear preceded the southeastward transport of angular momentum and cyclonic vorticity into the United States. b. Temperature anomalies showing the eastward shift of warm air and the initiation of cooling in the Far West as polar maritime air began its penetration. c. Precipitation totals (in inches) indicate continuation of the drought but with significant amounts appearing in the Far Northwest.

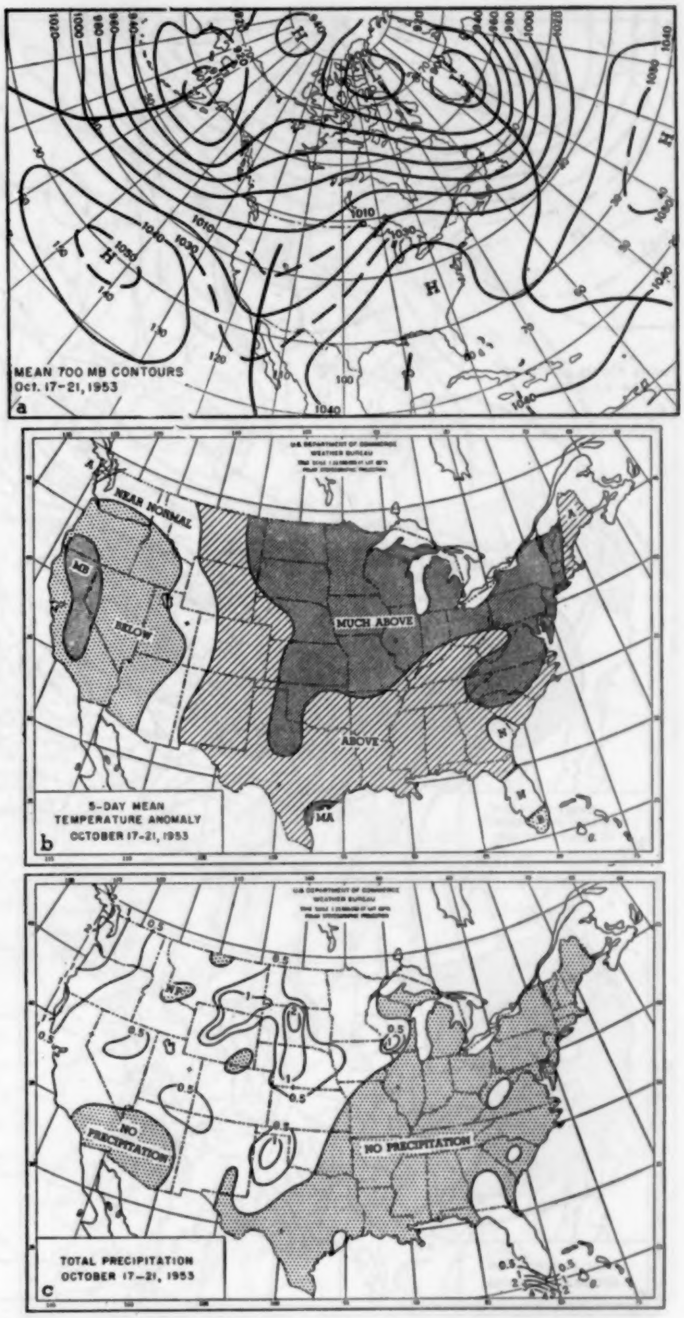


Figure 2.—Five-day means for October 17-21, 1953, 1 week later than figure 1. a. 700-mb. heights in tens of feet. Note increase of westerlies and cyclonic vorticity over western United States. Ridge has advanced eastward and no longer prevents advection of moisture from the Gulf of Mexico. b. Temperature anomalies. Cold and warm temperature anomalies shifted eastward with upper level circulation features and cold maritime air dominated in the West. c. Precipitation totals (in inches) show spread of precipitation eastward as trough advanced alleviating drought in many areas.

at lower latitudes, had shifted eastward to the Appalachians and tilted northwestward through central Canada.

Figures 2b and 2c show the results of these circulation changes on the weather. Polar maritime air effected below normal temperatures over most of the Far West in the upper level trough. Above and much above normal temperatures were generally found throughout the large ridge system over the East and in the southwesterly flow ahead of the trough. A more significant change is evident in the precipitation pattern which shows that the rains spread from the Pacific Coast to the Panhandle and northeastward to the upper Mississippi Valley. Areas with a half inch or more, while fairly numerous and occasionally extensive, failed by far to cover all of the western drought area. Nevertheless, this represented the most extensive spread of appreciable precipitation in over a month and revived the hopes of hard-hit agricultural interests. At the beginning of this period (October 17)

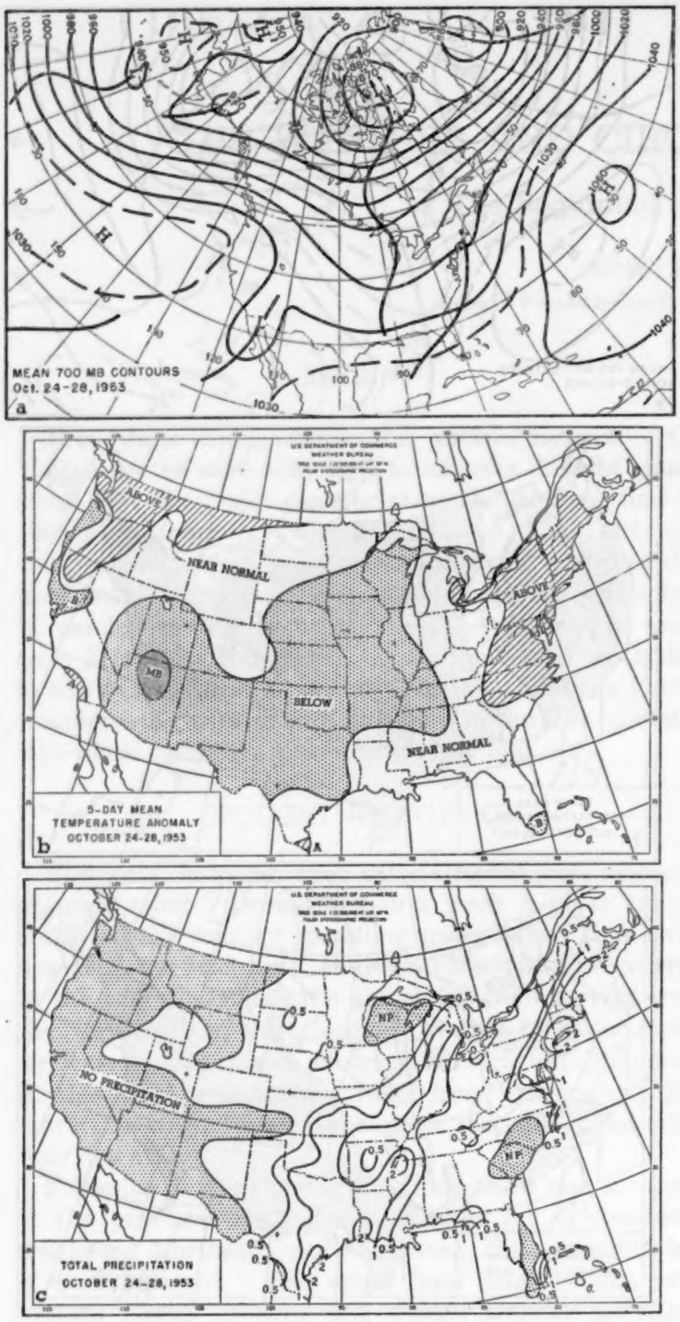


Figure 3.—Five-day means for October 24–28, 1953, 1 week later than figure 2. a. 700-mb. height in tens of feet. Absorption of major portions of the United States trough into the main westerly belt was accompanied by another trough shear and widespread cyclonic circulation in the United States. b. Temperature anomaly pattern is almost the reverse of that in figure 1b and accompanies circulation changes cited. c. Precipitation totals (in inches). Widespread precipitation associated with the upper level cyclonic circulation occurred in significant amounts and ended the drought in many localities.

and later on the 26th, the Mississippi River at Memphis reached the lowest stage (−3.3 feet) in 80 years of record.

The mean map 1 week later, October 24–28 (fig. 3a) shows the subsequent transition. As the trough intensified in the central Pacific a strong ridge built up along the west coast, particularly at middle latitudes. This development was accompanied by a rapid eastward motion of the portion of the United States trough which sheared completely from the low-latitude piece over Lower California and the southern Colorado River Valley. During this time the western Atlantic trough of the previous week became cut off, retrograded as a closed Low and, as shown here, finally weakened and was absorbed again into the westerly stream. The result was a broad area of cyclonic circulation over central and eastern areas of the United States.

Further extension of the cold air into central and southwestern United States accompanied this change as shown in figure 3b. While cooling itself usually mitigates drought conditions, the more important effect was the eastward spread of precipitation. Figure 3c shows appreciable precipitation over central and northeastern areas, with lesser amounts over much of the Appalachian region.

In summary: Many of the areas suffering intense drought received real relief during October. Precipitation was quite widespread (see Charts II and III) but not everywhere adequate for general relief. Temporarily at least, the drought was assuaged, but continued precipitation would be necessary to prevent immediate reintensification.

The effect of the drought on agriculture varied greatly with the locale and the main crop or activity. Paradoxically, the country's principal crops were excellent. Major corn areas were north of the most intense drought or the crop was too far advanced to be ruined by late summer aridity. Cotton survived with less weevil infestation partially making up for the drier weather. Wheat had been far enough along to mature where affected, and the rains came early enough so that fall seeding or reseeding held fair prospects. The cattlemen, in general, were hardest hit where pastures browned off and feed and water were scarce. In the East, extensive damage to smaller crops was fairly common. However, a fall drought insures good harvesting weather and in essence the total agricultural product was well above normal and harvested in record time.

MONTHLY CIRCULATION FEATURES

As a result of the marked transitions just discussed the monthly average contours (fig. 4) at 700 mb. lacked strong definition over the United States. A weak trough in the Far West and a slack gradient at lower latitudes across the United States were the reflection of these changes. The major North American characteristic was an above normal height anomaly center (+250 feet) over Ontario, Canada, which indicates the North American westerlies were farther north and stronger than normal over Canada and much weaker than normal over the United States. Figure 5, the standardized deviations of the mean heights, reveals that the Canadian anomaly center was greater than twice the standard deviation, a highly significant departure.

Inspection of adjacent areas shows the Pacific dominated by broad cyclonic circulation, strong westerlies, and greater storm activity than usual in the Gulf of Alaska.

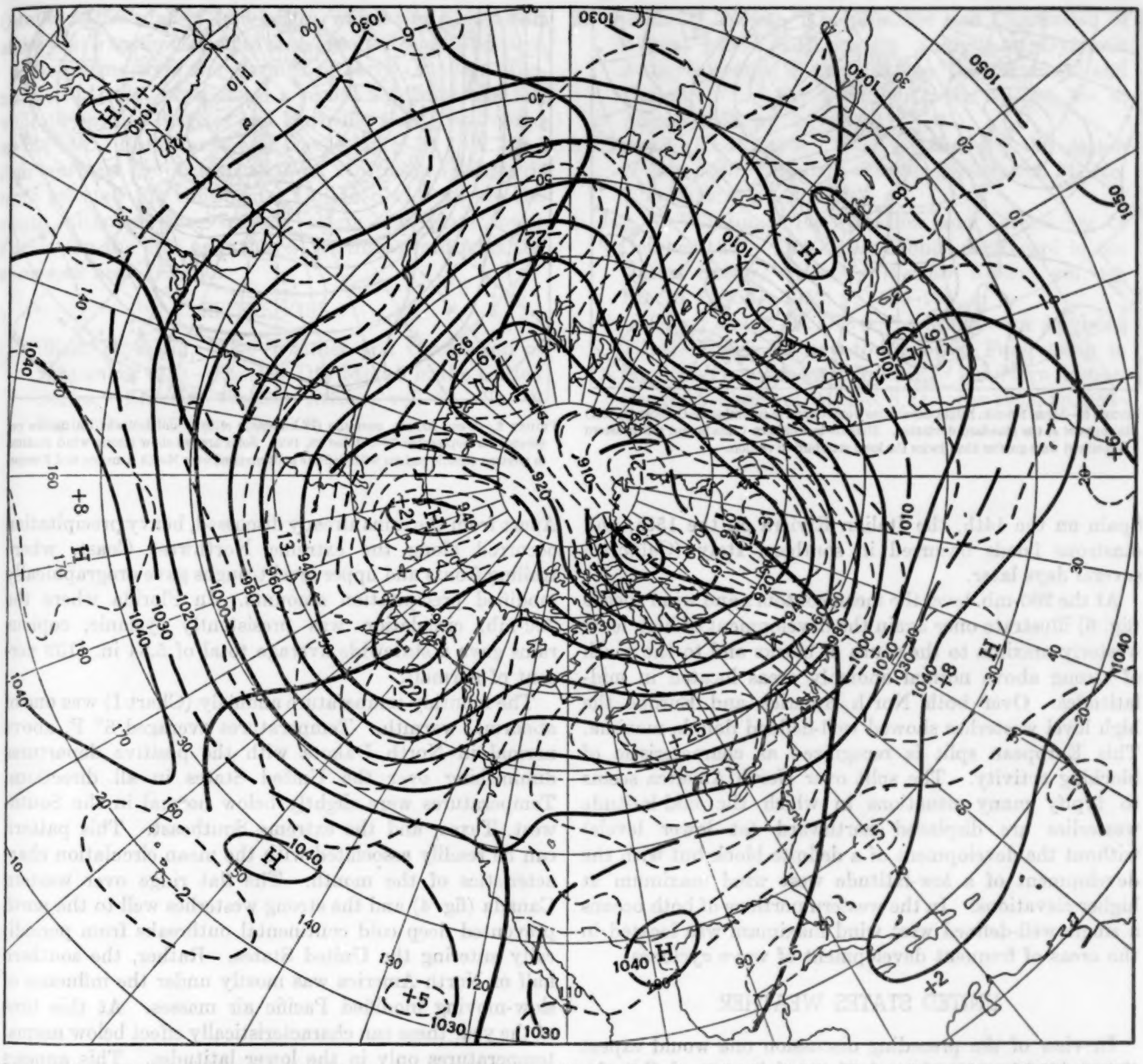


FIGURE 4.—Mean 700-mb. height contours and departures from normal (both in tens of feet) for September 29–October 28, 1953. Weak gradients and poor definition of pattern features over southern United States were reflections of transitions within the month. Abnormally strong Aleutian and Icelandic Lows accompanied oceanic high index regimes. Westerlies over North America were farther north and stronger than normal with heights averaging 250 feet above normal in south-central Canada. Note blocking over Europe and associated low latitude westerlies in Mediterranean.

The Gulf Low was remarkably persistent—sea level pressures averaged 6 mb. below normal (Chart XI)—and the numerous individual cyclones which contributed to this activity are tracked on Chart X. Quite a few of these impulses crossed the Canadian mountain regions (at the surface and/or aloft) and gave rise to eastward moving cyclones in the fast westerlies across Canada. Some of these storms contributed to cyclonic activity in the Davis Strait while others, passing south of Greenland, were joined by northeastward moving storms from the Atlantic Coast trough (fig. 4) and led to intense cyclonic activity near Iceland (see Charts X and XI). This was the area of the greatest standardized departure from normal, i. e., 2.2σ.

Europe was the scene of recurrent surges of blocking. Heights averaged 280 feet above normal over the Baltic Sea area. Typical fast westerlies carried many perturbations over the top of the ridge. To the south, in the Mediterranean, a characteristic (of blocking) low-latitude Low was associated with repeated cyclonic activity. Heavy rains and widespread flooding—the result of these slow-moving perturbations—were reported from northern

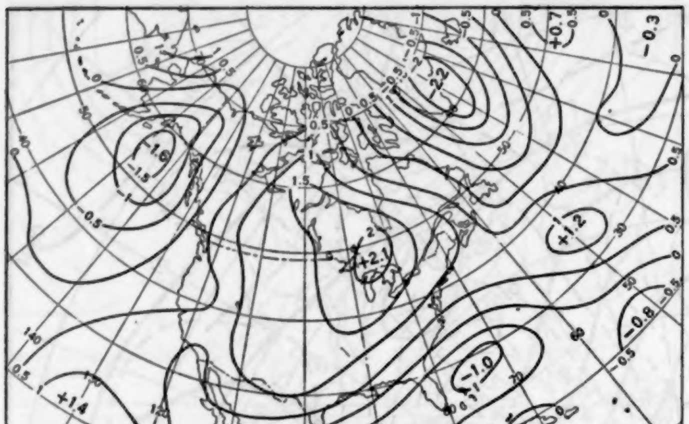


FIGURE 5.—Mean 700-mb. height departures from normal (September 29–October 28, 1953) in units of σ, the standard deviation. Heights in southern Canada and southeastern Greenland were greater than twice the local standard deviation.

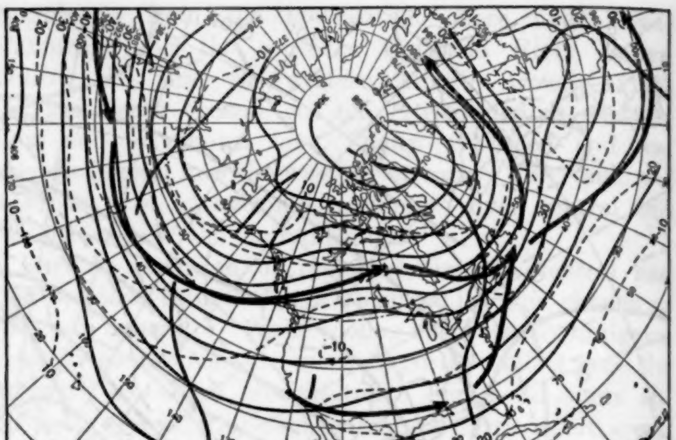


FIGURE 6.—Mean 200-mb. contours (in hundreds of feet) and isotachs (in meters per second) for September 29–October 28, 1953. Solid arrows show strong wind maxima in western oceanic regions with definite split maxima over North America and Europe.

Spain on the 14th, the Italian Riviera on the 15th, and diastrous floods occurred in southern Italy (Calabria) several days later.

At the 200-mb. level the mean contours and wind speeds (fig. 6) illustrate once again the development of high level westerly maxima to the south of blocks and to the south of strong above normal anomaly areas located in mid-latitudes. Over both North America and Europe the high level westerlies showed well-defined double maxima. This European split is recognized as characteristic of blocking activity. The split over North America seems to typify many situations in which the mid-latitude westerlies are displaced northward (at lower levels) without the development of a definite block but with the development of a low-latitude west wind maximum at higher elevations. In the western portions of both oceans a single well-defined west wind maximum was located in the areas of frequent development of wave cyclones.

UNITED STATES WEATHER

In view of the preceding discussion one would expect the major storm track to be located in central Canada, north of the maximum west winds, with relatively little cyclonic activity over the United States. Chart X reveals that relatively few cyclones occurred within the United States borders. Conversely, south of the west wind maximum, anticyclonic passages were quite frequent (Chart IX) in the region of anticyclonic relative vorticity at 700 mb. (not shown).

Under this general regime widespread excessive precipitation would be inconsistent with observed circulation. Charts II and III show that while many States received drought-moderating precipitation, a majority of States had less than normal amounts. Most of the significant precipitation has been mentioned in the preceding pages. Apart from the rains already discussed, heavy precipitation occurred along the extreme Northwest Coast, where trailing fronts and upper level troughs gave orographically modified precipitation amounts. In Florida where the 700-mb. circulation was presistently cyclonic, copious rains gave a statewide average total of 5.84 in. (139 percent of normal).

The monthly temperature anomaly (Chart I) was one of abnormal warmth. Temperatures averaged 8° F. above normal in North Dakota with the positive departures diminishing over the United States in all directions. Temperatures were slightly below normal in the Southwest, Texas, and the extreme Southeast. This pattern can be readily associated with the mean circulation characteristics of the month. The flat ridge over western Canada (fig. 4) and the strong westerlies well to the north prevented deep cold continental outbreaks from periodically entering the United States. Rather, the southern half of North America was mostly under the influence of slow-moving modified Pacific air masses. At this time of the year these can characteristically effect below normal temperatures only in the lower latitudes. This appears well related to the observed pattern except perhaps for Florida where persistent cloudiness and rain provided the cooling mechanism (Charts VI and VII).

NEWSWORTHY ASPECTS OF THE WEATHER

Drought and its variations, recessions, and advances were continuously in the news throughout the month. Announcements of a Federal drought aid program, applications for assistance, closing of public lands and national forests to hunting and recreation, failure of wells, and lowering of water tables—all were commonly met news stories. The drought's alleviation was commensurately popular and items such as Amarillo's 2-week total (ending

October 26) rainfall of 4.56 inches, which was almost half of the year's accumulation to date, received wide attention.

Other items were the warmth of early October. Bismarck, N. Dak., experienced a record 95° F. on the 1st, while 101 at Los Angeles and Burbank, Calif., was noted on the 5th. Both Fargo and Devils Lake, N. Dak., had their warmest October on record. No full-fledged hurricanes affected the continental United States during the month although one tropical storm did cross lower Florida (on the 9th) as it moved northeastward from the warm seas near Yucatan.

REFERENCES

1. William H. Klein, "The Weather and Circulation of September 1953—Another Dry Month in the United States," *Monthly Weather Review*, vol. 81, No. 9, September 1953, pp. 304–308.
2. William H. Klein, "The Weather and Circulation of August 1953—Featuring an Analysis of Dynamic Anticyclogenesis Accompanying Record Heat and Drought," *Monthly Weather Review*, vol. 81, No. 8, August 1953, pp. 246–254.
3. Harry F. Hawkins, Jr., "The Weather and Circulation of July 1953," *Monthly Weather Review*, vol. 81, No. 7, July 1953, pp. 204–209.
4. Jay S. Winston, "The Weather and Circulation of October 1952—The Driest Month on Record in the United States," *Monthly Weather Review*, vol. 80, No. 10, October 1952, pp. 190–194.
5. V. J. Oliver and M. B. Oliver, "A Method for Applying Tilted-Trough Theory to Synoptic Forecasting in the Mid-Troposphere," *Bulletin of American Meteorological Society*, vol. 34, No. 8, October 1953, pp. 368–375.

CYCLOGENESIS ALOFT OVER SOUTHWESTERN UNITED STATES, OCTOBER 17–22, 1953

CLARENCE L. KIBLER AND EARL F. ROBINSON
WBAN Analysis Center, U. S. Weather Bureau, Washington, D. C.

INTRODUCTION

During the first 2 weeks of October 1953 storms entered the North American continent from the Pacific at latitudes north of 50° N. This is very clearly shown by the October storm tracks (Chart X). With the main storm centers passing rapidly eastward through Canada, only weak frontal systems were found over the United States, one of which brought significant rainfall to some sections of the Middle West and Northeast. Under these high index conditions, generally high pressures prevailed throughout the United States and the resultant weather, with the exception noted, could be termed generally fair.

As evidence of the "fair" condition prevailing over the country, the following is quoted from the *Weekly Weather and Crop Bulletin* for the week ending October 19: "Severe droughty conditions still persist over practically the entire country. . . . For the last 10 weeks the total precipitation did not exceed one-half of the normal in most of the interior and far Southwest, with less than 25 percent over much of the Ohio and middle Mississippi Valleys, most of Missouri and Iowa, in a narrow belt from southern Minnesota westward to northeastern Nevada, and in extreme southern portions of California, Arizona, and New Mexico" [1].

SYNOPTIC DEVELOPMENT

In mid-October the weather pattern began to shift from high to low index. The large dominant Aleutian Low began to split. One cell took up a position in the Kamchatka region while the other cell moved southeastward to the Gulf of Alaska.

The surface map for 0030 GMT, October 18 (fig. 1) illustrates the surface pattern during this change period. The Gulf of Alaska Low was well established, but the pattern over Canada still resembled the high index situations. The front through the central United States was very weak and had yielded only spotty precipitation.

The front on the west coast was the first of the systems under the changing regime. The 500-mb. chart, figure 2, for 0300 GMT, October 18 indicates that very cold air had already passed east of ship Papa (50° N., 145° W.). This cold air, according to reconnaissance flight reports had moved eastward south of ship Papa.

The 500-mb. prognostic chart prepared at WBAN Analysis Center from the 0300 GMT, October 18 chart (fig. 2) forecast continued eastward movement of the cold air to a Pocatello-Las Vegas-San Diego line by 1500 GMT, October 19. Some deepening was anticipated but not to the degree encountered. The constant absolute vorticity trajectory as constructed by the Wobus differential analyzer [2] was in agreement with the prognostic chart.

The jet stream at 500 mb. at 0300 GMT, October 18 was approximately along the 18,400-foot contour line. As the

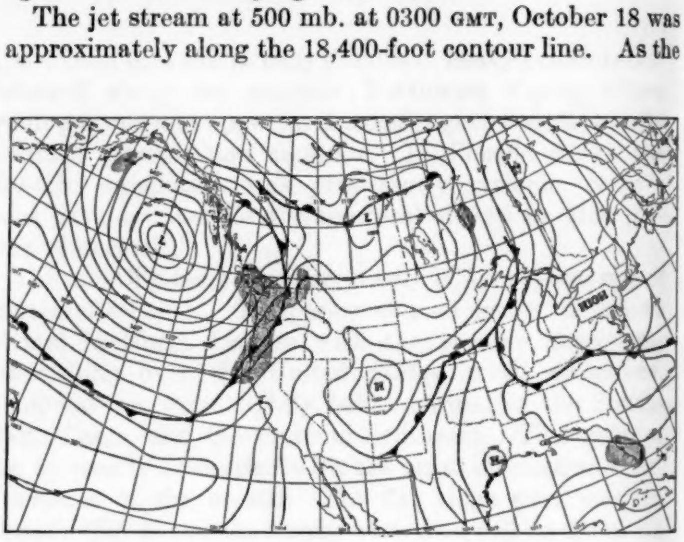


FIGURE 1.—Surface chart for 0030 GMT, October 18, 1953. Isobars (solid lines) are drawn for 3-mb. intervals.

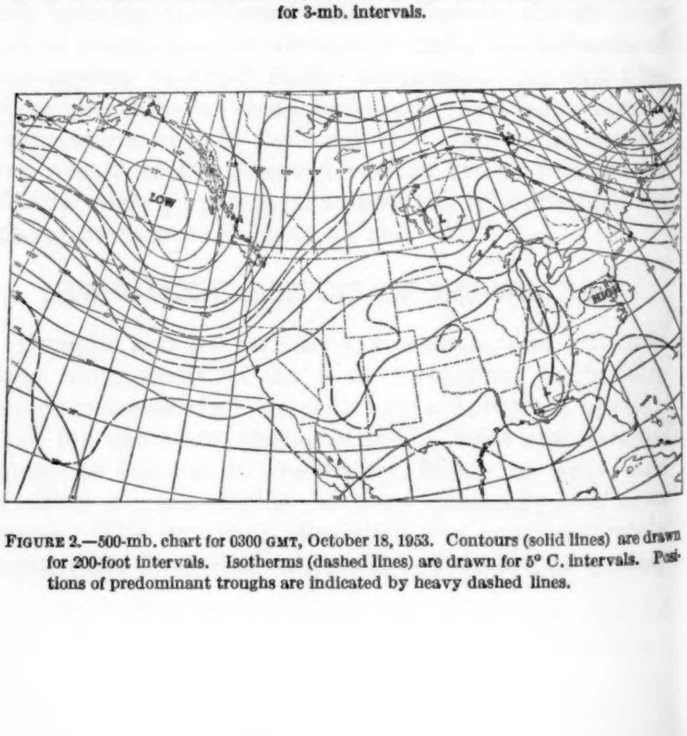


FIGURE 2.—500-mb. chart for 0300 GMT, October 18, 1953. Contours (solid lines) are drawn for 200-foot intervals. Isotherms (dashed lines) are drawn for 5° C. intervals. Positions of predominant troughs are indicated by heavy dashed lines.

jet approached the west coast it came into a divergent contour field and by Scherhag's rule, as quoted by Alaka et al. [3], "cyclones develop . . . in a delta region, i. e., a region where the upper contours diverge." The 12-hour pressure change charts at 0030 GMT, October 18 (not shown) indicated a large fall area over southwestern Canada and western United States, an area eventually associated with the cylogenesis of the storm under discussion.

RAPID CYCLOGENESIS ALOFT

A process further adding to the development over California and Nevada was to be found upstream, over the Pacific. Along the 43d parallel, a deep wave cyclone had been moving eastward at 22 knots. Deep warm air was being transported northward ahead of the system and mid-troposphere contour heights began to rise sharply. Ship Papa's 500-mb. height rose 740 feet in the 24 hours ending 1500 GMT, October 18. By 0300 GMT, October 19 (fig. 3) this rise area had been propagated downstream and was centered at about 46° N., 135° W. The rapid ridging to the west of the deepening trough resulted in the cold air, represented by the −25° C. isotherm (figs. 2 and 3), being thrust sharply southward into Nevada.

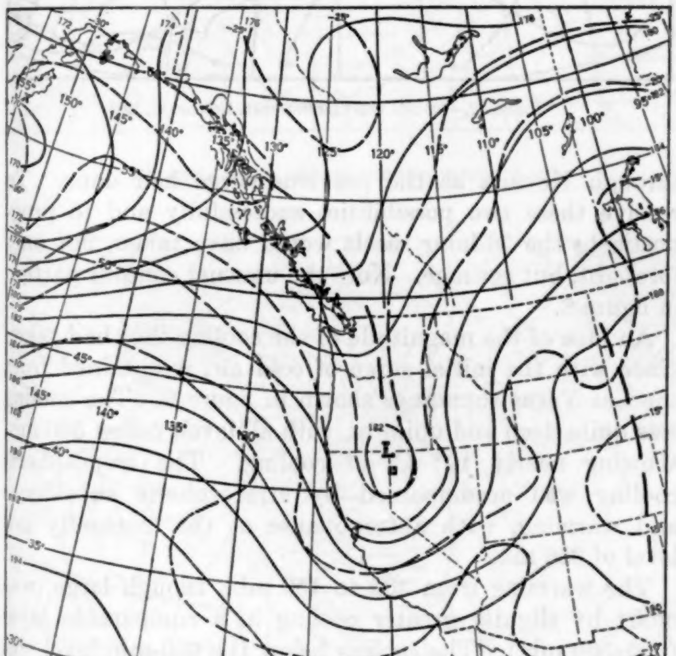


FIGURE 3.—500-mb. chart for 0300 GMT, October 19, 1953.

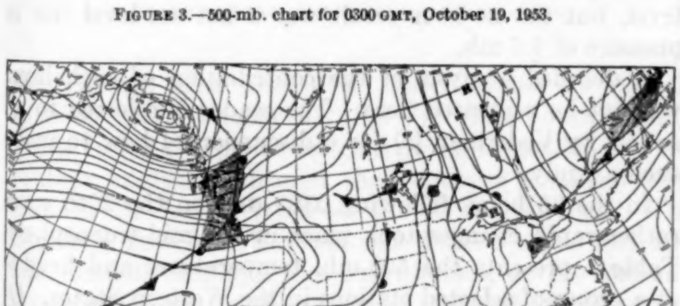


FIGURE 4.—Surface chart for 0030 GMT, October 20, 1953.

As the cold air moved inland, surface pressures over the Pacific Northwest rose sharply and an extension of the Pacific High moved onshore. The cold surface air, topped by rising contour heights at the 500-mb. level served to maintain relatively high surface pressures over Washington and Oregon in spite of a rapidly approaching frontal system (fig. 4). One unconfirmed tornado was recorded as the cold air moved over Fowler, Colo. on the 20th.

The jet stream at 500 mb. at 0300 GMT, October 19 (fig. 3) in the vicinity of Oakland, in the southwest quadrant of the Low, progressed by 1500 GMT October 19 to near Long Beach, south-southwest of the Low as it began to curve more southeasterly. This substantiates an observation by Riehl [4] that "As long as a jet stream maximum . . . is situated or moves on the west side of an upper low, this low will not come out and it will strengthen."

To forecast the 500-mb. pattern from the chart for 0300 GMT on the 20th (fig. 5) it was necessary to note the change of the isobar-isotherm relationship that had taken place in the region just west of Annette, Alaska and Tatoosh, Wash. Strong warm air advection indicated for Tatoosh at 0300 GMT, October 19 (fig. 3) had, at 0300 GMT on the 20th (fig. 5), been replaced by cold air advection. Similar advection patterns prevailed throughout the troposphere with the reverse thermal advection above the tropopause.

That the period of cold air advection had just begun was evident from the data at hand. Between 0300

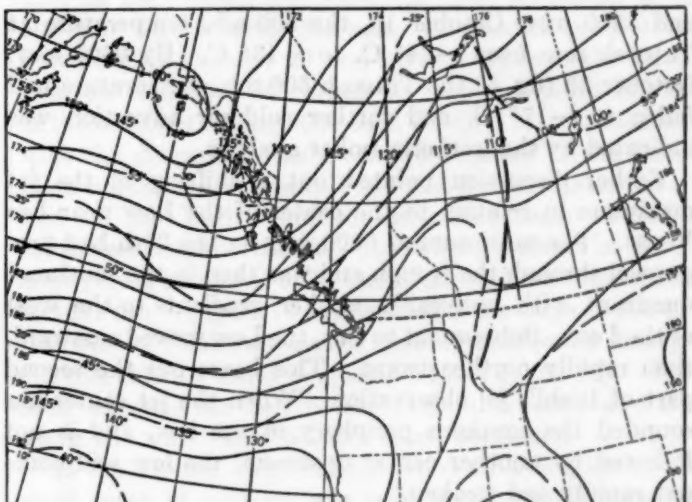


FIGURE 5.—500-mb. chart for 0300 GMT, October 20, 1953.

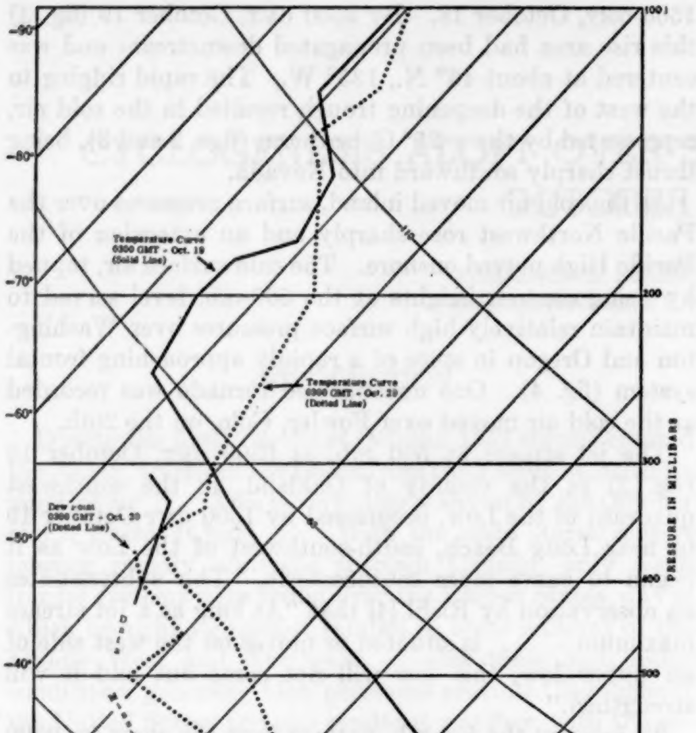


FIGURE 6.—Upper air soundings over Las Vegas, Nev. at 0300 GMT, October 19, and 0300 GMT, October 20, 1953.

and 1500 GMT, October 19, the 500-mb. temperature at Tatoosh rose from −24° C. to −13° C. By 0300 GMT, October 20 (fig. 5) the Tatoosh 500-mb. temperature had fallen to −17° C. and further cold air advection was indicated by the isotherm-isobar analysis.

Earlier discussion pointed out a shifting of the jet maximum in relation to the center of the Low near Las Vegas. The maximum at 0300 GMT on the 20th had progressed through the trough and was then in the southeast quadrant with noticeably weaker gradients to the west of the Low. Subsequent to this, the Low moved eastward, then rapidly northeastward. This bears out the second part of Riehl's [4] observation, "When the jet center has rounded the southern periphery of the low, and is not followed by another center upstream, the low will come out rapidly and weaken."

A continuity chart maintained at the WBAN Analysis Center indicates longitude 110°-120° W. is a major trough area. With the movement of the Low near Las Vegas eastward, and with strong cold air advection in the Annette-Tatoosh region, the forecaster was confronted with a major problem as to whether the cold air would move eastward through Montana or drop southward

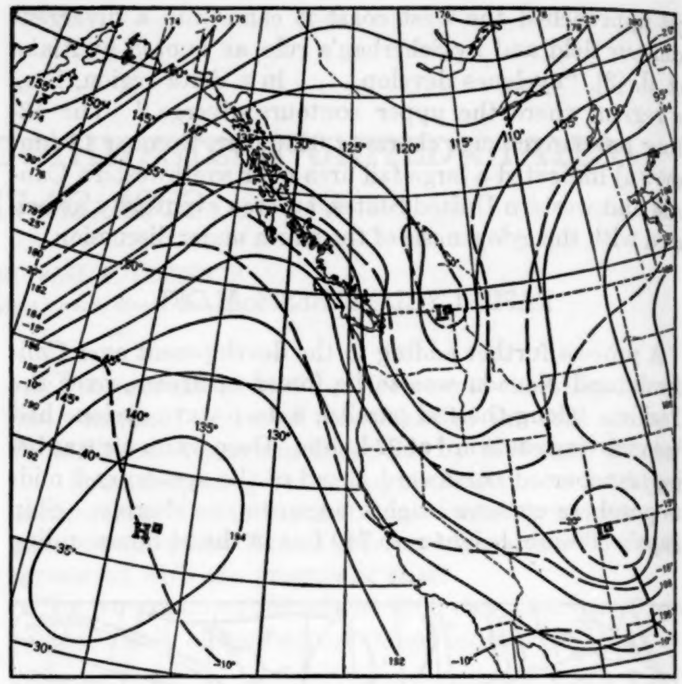


FIGURE 7.—500-mb. chart for 0300 GMT, October 21, 1953.

through Nevada as the previous surge had done. To resolve these two possibilities successfully and to prognosticate the 36-hour result would have taken, not only foresight, but courage. Note the unusual contour pattern in figure 8.

An idea of the magnitude of the cooling that had taken place with the initial surge of cold air, is obtained from the Las Vegas soundings shown in figure 6. The cooling was quite deep and uniform, with all levels below 300 mb. showing nearly 10° C. of cooling. The tropospheric cooling was accompanied by stratospheric subsidence and warming, with a tropopause at the unusually low level of 350 mb.

The warming from 300 to 150 mb., though large, was offset by slightly greater cooling in a comparable layer (600–300 mb.). The cooling below the 600-mb. level was partially nullified by the warming above the 135-mb. level, but the 24-hour result was a net sea-level rise in pressure of 9.5 mb.

A detailed analysis of the contribution of each layer will not be presented here. The reader is referred to an article by Vederman [5] for a discussion of how to make such a study.

In the 36 hours following 0300 GMT on the 20th some rather rapid changes took place in the mid-troposphere. Table 1 presents the 500-mb. temperatures and heights at a group of selected stations in the Western States. Of interest are the rapid changes at these stations. Note the succession of warming and cooling at Ely, Nev., as the first cold surge moved eastward and the second thrust down from the north. A temperature and height forecast for any of these stations would have been a taxing assignment.

Worthy of particular note is the change of flow over

Table 1.—*500-mb. heights and temperatures at selected stations in western United States, Oct. 19–22, 1953*

Date	Time	Tatoosh, Wash.		Medford, Oreg.		Santa Maria, Calif.		Boise, Idaho		Ely, Nev.		Las Vegas, Nev.		Phoenix, Ariz.	
	GMT	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*
Oct. 19	0300	18,170	−24	18,310	−24	18,400	−13	18,360	−19	M	(−20)	18,740	−10	19,060	−10
	1500	18,610	−13	18,830	−10	18,770	−9	18,610	−17	18,400	−20	18,150	−22	18,080	−13
Oct. 20	0300	18,570	−17	19,090	−12	18,920	−9	18,810	−13	18,620	−18	18,330	−21	18,550	−20
	1500	18,280	−27	18,800	−16	19,050	−11	18,750	−15	18,710	−13	18,570	−18	M	(−19)
Oct. 21	0300	18,660	−20	18,840	−17	19,030	−13	18,280	−25	18,570	−16	18,820	−15	18,900	−12
	1500	18,960	−21	18,810	−18	18,980	−15	18,260	−27	18,240	−26	M	(−18)	18,870	−13
Oct. 22	0300	19,170	−16	18,820	−16	18,360	−17	18,530	−23	18,220	−27	18,270	−24	18,730	−17
	1500	19,170	−14	18,730	−17	18,280	−19	18,580	−21	18,320	−22	18,110	−24	18,620	−17

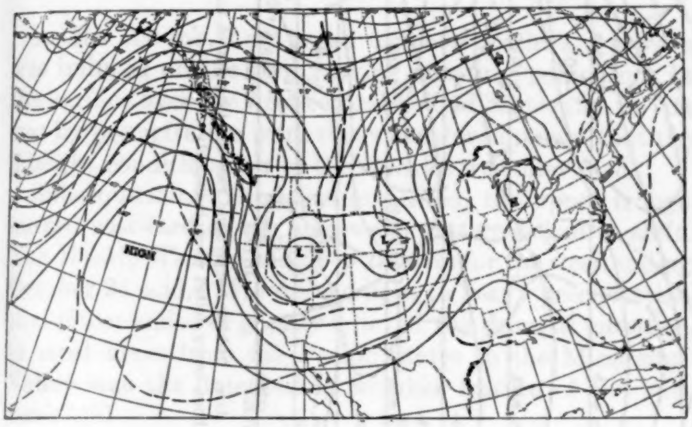


Figure 8.—500-mb. chart for 1500 GMT, October 21, 1953.

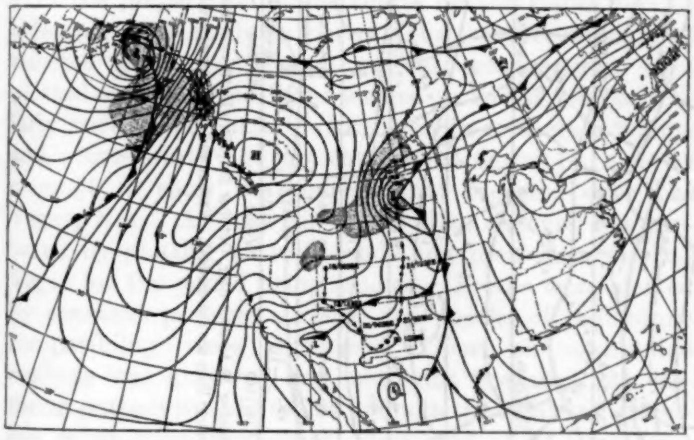


Figure 9.—Surface chart for 0030 GMT, October 22, 1953.

the Tatoosh area from 0300 GMT, October 20 (fig. 5) to 0300 GMT, October 21 (fig. 7). The southwesterly winds veered sharply as the cold air came onshore and the contour analysis indicated that stronger northerly flow had, in 24 hours, replaced the southwesterlies. The northerly flow over Tatoosh was definite up to 300 mb. and existed, although was less obvious, at the 200-mb. level. Once the northerlies were established the events following were more easily anticipated.

In line with the views expressed by Wobus and Norton [6] and employed by O'Connor and Norton [7] the strong northerly current entering northern California contributed a portion of its kinetic energy toward deepening.

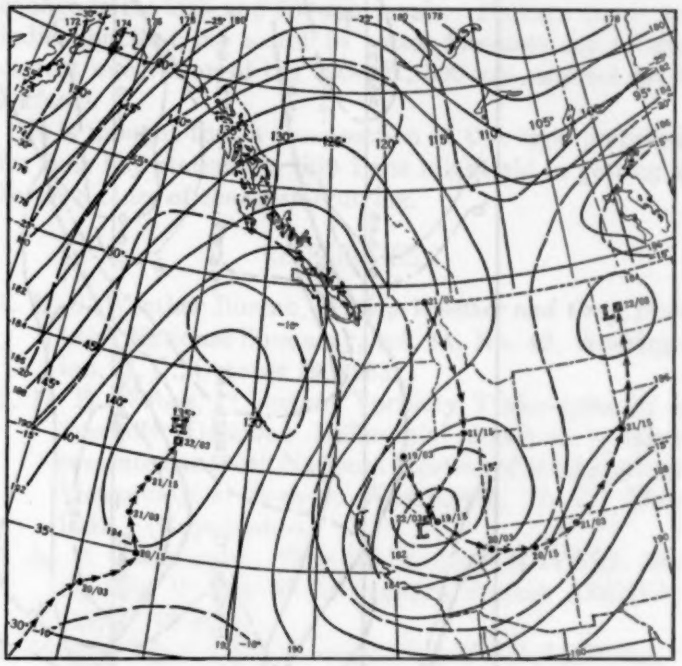


Figure 10.—500-mb. chart for 0300 GMT, October 22, 1953.

On October 18 attention was directed to a deepening Low in the Pacific, and its effect upon deepening of the 500-mb. trough over Nevada. A parallel process was occurring on October 20 and 21 as a wave in the Pacific near 35° N., 160° W. began to deepen rapidly (20 mb. in the 30 hours ending 0630 GMT, October 21). Associated with the deepening was the rapid building of the Pacific High northward over ship Papa and a reorientation of the axis of the High from southwest-northeast to south-southwest-northnortheast. Its central pressure in the 30-hour period ending at 0630 GMT, October 21 rose from 1030 to 1041 mb. Figure 10 indicates that the ridge at 500 mb. just west of California moved steadily northward throughout this entire weather sequence (figs. 7, 8, and 10). With each advance northward, the ridge sharpened and flow along the west coast became more northerly.

As the 500-mb. ridge strengthened off-shore, the southward surge of cold air was facilitated. The events following 0300 GMT on the 21st occurred in rapid succession. By 1500 GMT on the 22d (fig. 8) the first Low moved from northwestern New Mexico to western Nebraska. An unusual feature of this system was that it had apparently begun to fill as it moved eastward through Arizona, but

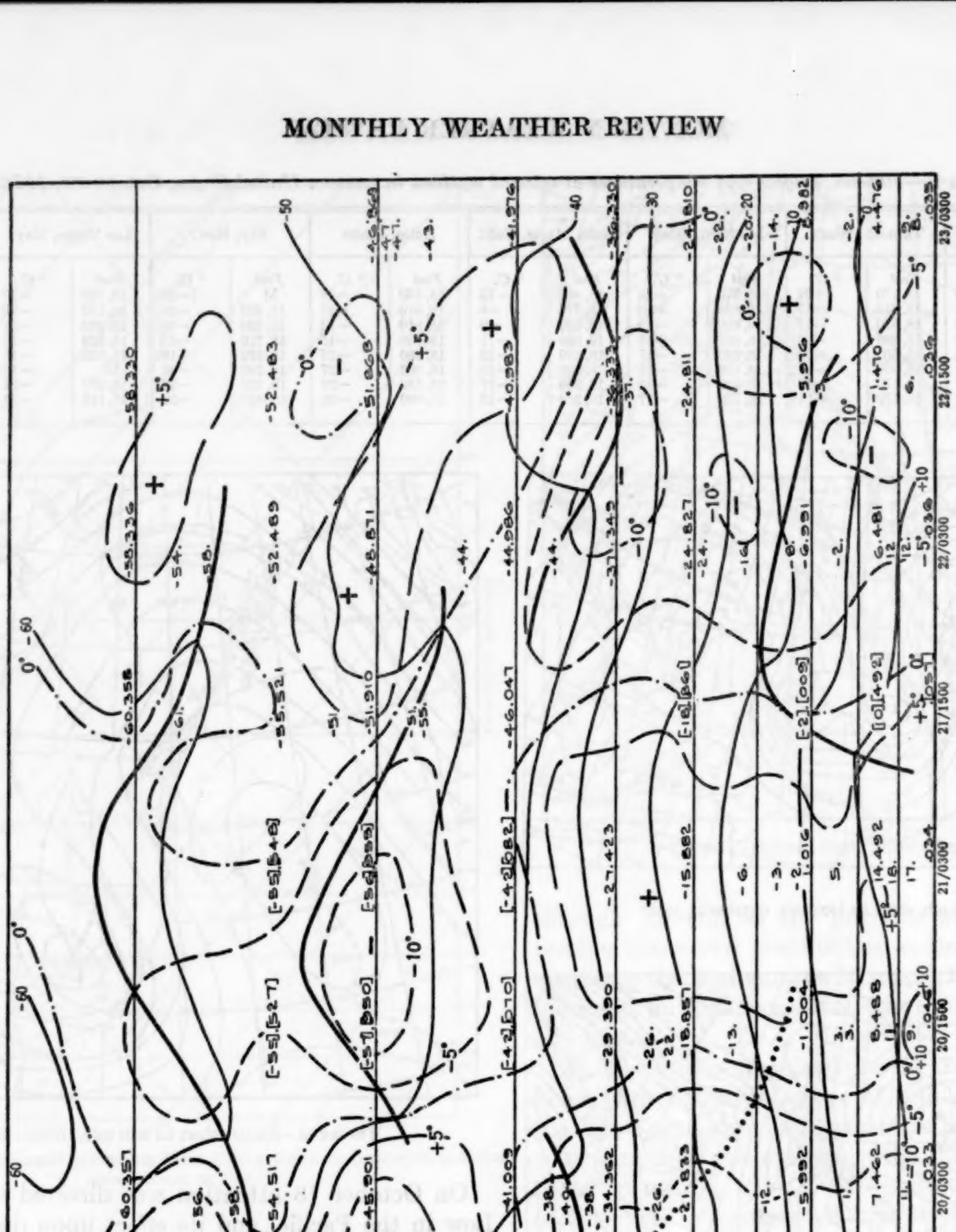


FIGURE 11.—Time cross-section for Las Vegas, Nev. from 0300 GMT, October 18 to 0300 GMT, October 23, 1953. Isotherms are light solid lines, 24-hour temperature rises are long dashes, temperature falls, short dashes, and zero temperature change lines are dot-dashed. Fronts and tropopauses are heavy solid lines, heavy dotted where indistinct.

suddenly redeveloped over Colorado as warm air was drawn into the eastern and northeastern quadrants.

Simultaneously the second system plunged almost straight south and developed a closed circulation near Elko, Nev., presenting a most unusual 500-mb. pattern. Twelve hours later (fig. 10) the first Low moved to a point northwest of Bismarck, N. Dak., as the second Low moved west-southwestward to Bishop, Calif.

BREAK IN DROUGHT CONDITIONS

As the 500-mb. Low began to move northward a wave was induced on the slow moving maritime-polar front at the surface over the west central United States (fig. 9). It was by precipitation from this wave development that the drought condition east of the Rockies was alleviated.

Subsequent to the charts presented, the upper trough moved eastward as the long-wave pattern began to shift. The *Weekly Weather and Crop Bulletin* for the week ending October 26 said, "Widespread light to heavy precipitation that either ended or greatly relieved the drought situation in most areas from the Pacific States to the Mississippi Valley was the outstanding weather feature of the past week" [8].

A SUGGESTED ANALYSIS TOOL

In the preparation of the charts for this paper various attempts were made to portray the weather changes at selected points. Although several cross-sections were plotted and analyzed, none seemed to do the job particularly well. One chart that evolved from these attempts and seems worthy of presentation is figure 11, a novel attempt to show the changes that occurred over Las Vegas, Nev. An analysis of the time changes was prepared by plotting all radiosonde and pibal data for Las Vegas for the period being studied. Fronts were located by constant pressure surface, and checks of radiosonde compatibility were performed. Once an acceptable analysis was achieved and isotherms prepared, the isotherm pattern was shifted 24 hours to the right and graphical subtraction performed. Isopleths of 24-hour temperature change were then available for the atmosphere at any fixed time over Las Vegas.

An examination of the atmosphere over Las Vegas at 1500 GMT on the 19th indicates that strong 24-hour temperature changes had occurred throughout the entire air column up to 100 mb. The level of no temperature change is just below the 300-mb. level. The 24-hour thickness change of the 1000 to 300-mb. layer was a thinning of 1060 feet, while the 300 to 100-mb. layer increased 1090 feet. Thus the cooling through seven-tenths of the atmosphere was more than nullified by warming in the two-tenths immediately above it. The 24-hour temperature change isopleths vividly point out the levels of warming and cooling.

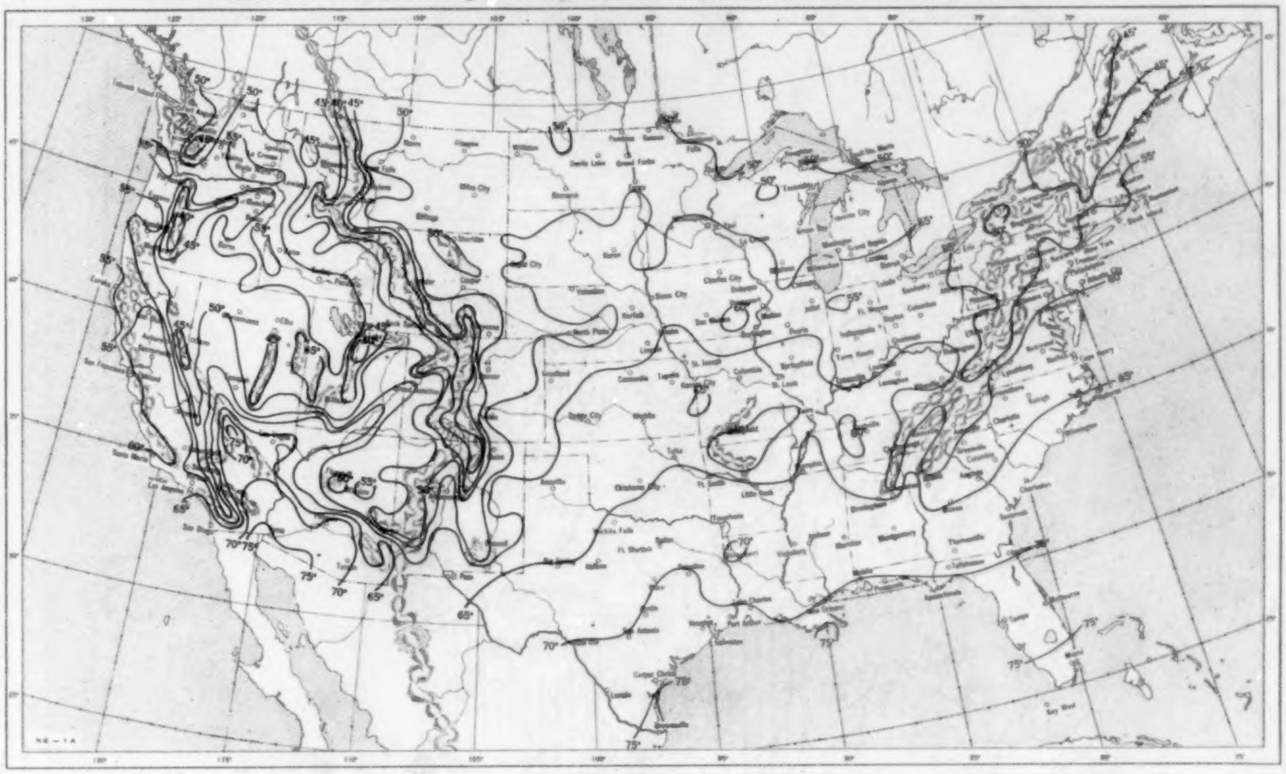
Noticeable is the closeness of the zero change line to the 300-mb. level and the closeness of centers of the maximum change to the 200- and 500-mb. levels. Perhaps this is an indication that the secret to better forecasts lies in the correct integration of the 200-mb., 500-mb., and sea-level surfaces.

It is thought that a cross-section of this type prepared for such key stations as ship Papa might aid in getting a better picture of changes occurring.

REFERENCES

1. U. S. Weather Bureau, *Weekly Weather and Crop Bulletin*, National Summary, vol. 14, No. 42, Washington, D. C., October 19, 1953.
2. H. B. Wobus, "Constant Vorticity Trajectories by a Specially Designed Differential Analyzer," paper presented at 110th National Meeting of the American Meteorological Society, Washington, D. C., May 1951. (Unpublished.)
3. M. A. Alaka et al., "The Jet Stream," NAVAER 50-1R-249, Bureau of Aeronautics Project AROWA, June 1, 1953.
4. Herbert Riehl et al., "Forecasting in Middle Latitudes," *Meteorological Monographs*, vol. 1, No. 5, American Meteorological Society, June 1952, p. 21.
5. Joseph Vederman, "Changes in Vertical Mass Distribution over Rapidly Deepening Lows," *Bulletin of the American Meteorological Society*, vol. 30, No. 9, November 1949, pp. 303-309.
6. Hermann B. Wobus and Lewis C. Norton, "Some Synoptic Aspects of a Change in Weather Regime During February 1950," *Monthly Weather Review*, vol. 78, No. 2, February 1950, pp. 31-40.
7. James F. O'Connor and Lewis C. Norton, "A Late-Season Storm Over the Plateau Area," *Monthly Weather Review*, vol. 78, No. 6, June 1950, pp. 105-111.
8. U. S. Weather Bureau, *Weekly Weather and Crop Bulletin*, National Summary, vol. 14, No. 43, Washington, D. C., October 26, 1953.

Chart I. A. Average Temperature (°F.) at Surface, October 1953.



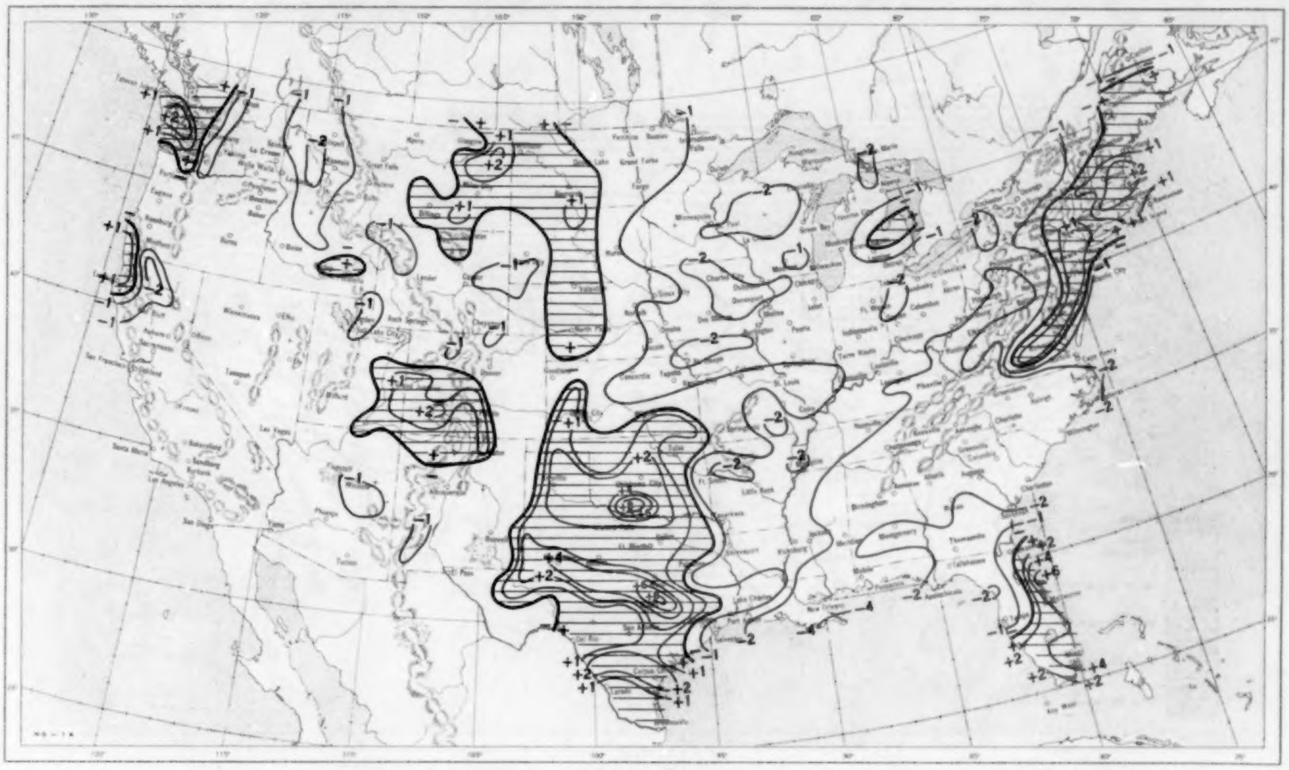
B. Departure of Average Temperature from Normal (°F.), October 1953.

A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), October 1953.

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

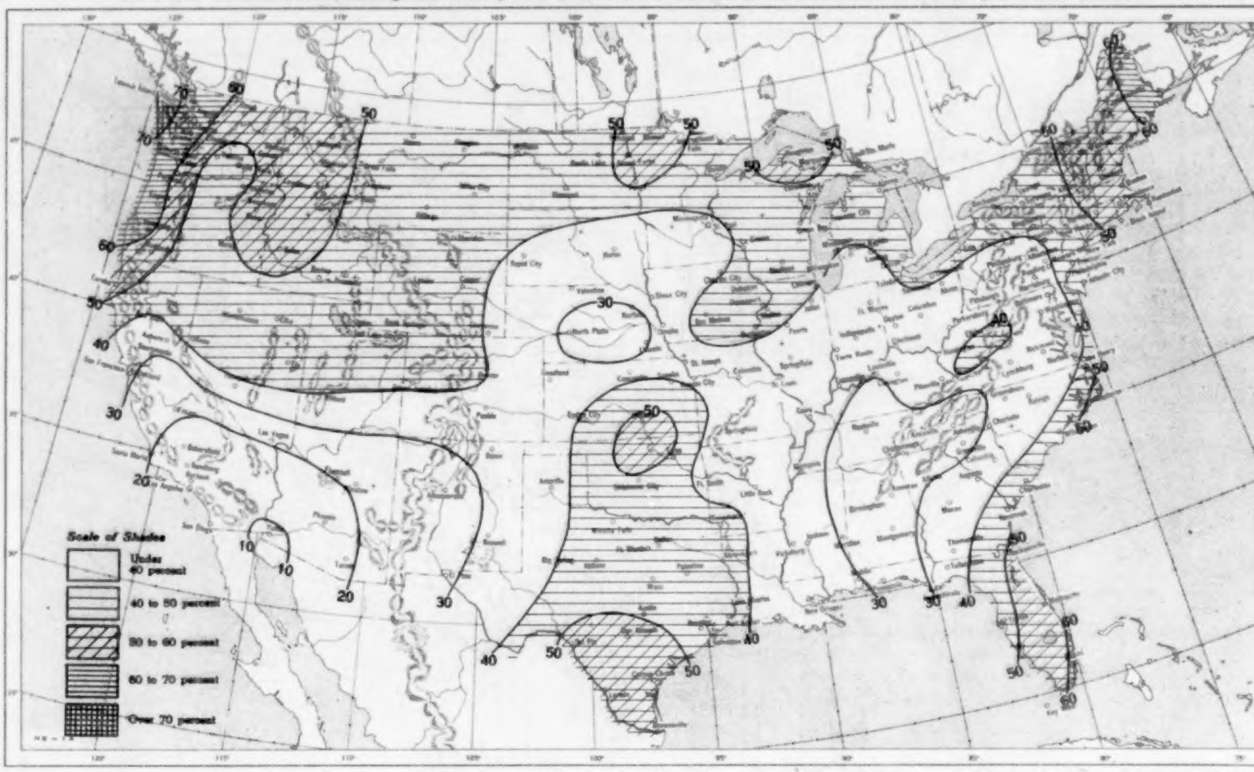
Chart III. A. Departure of Precipitation from Normal (Inches), October 1953.



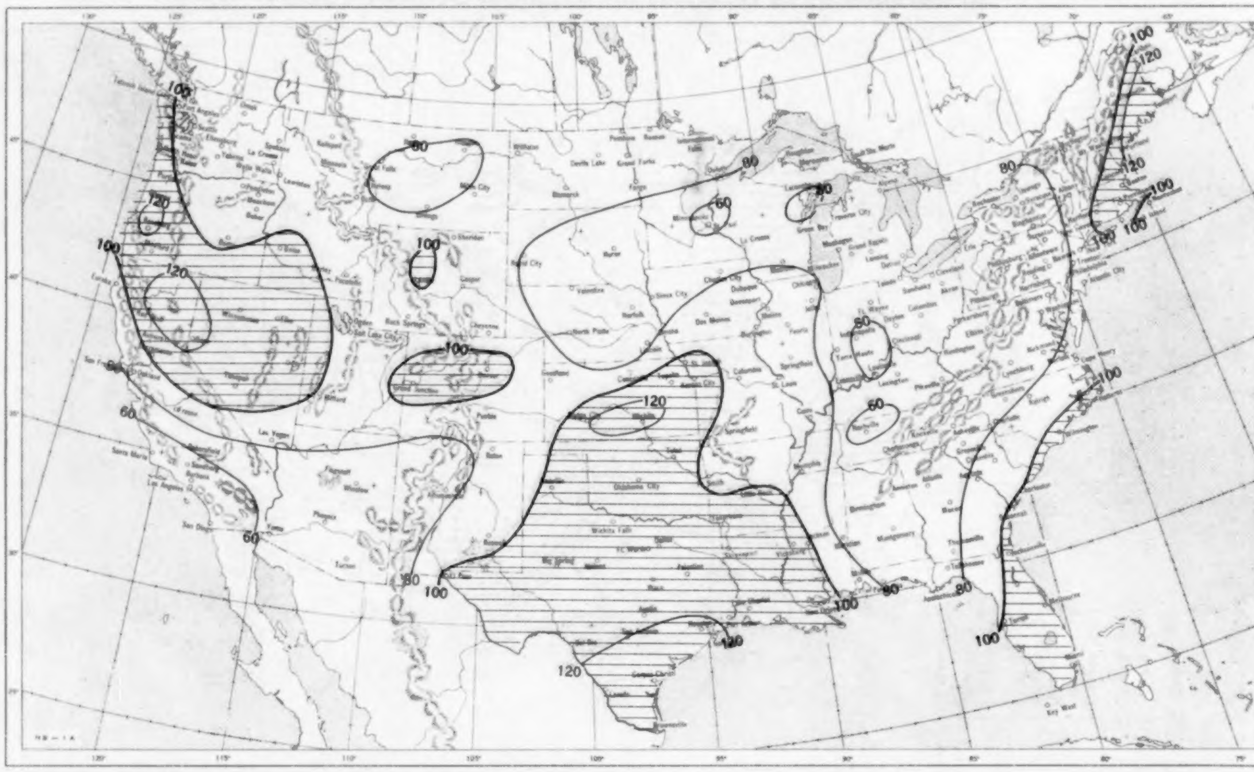
B. Percentage of Normal Precipitation, October 1953.

Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, October 1953.

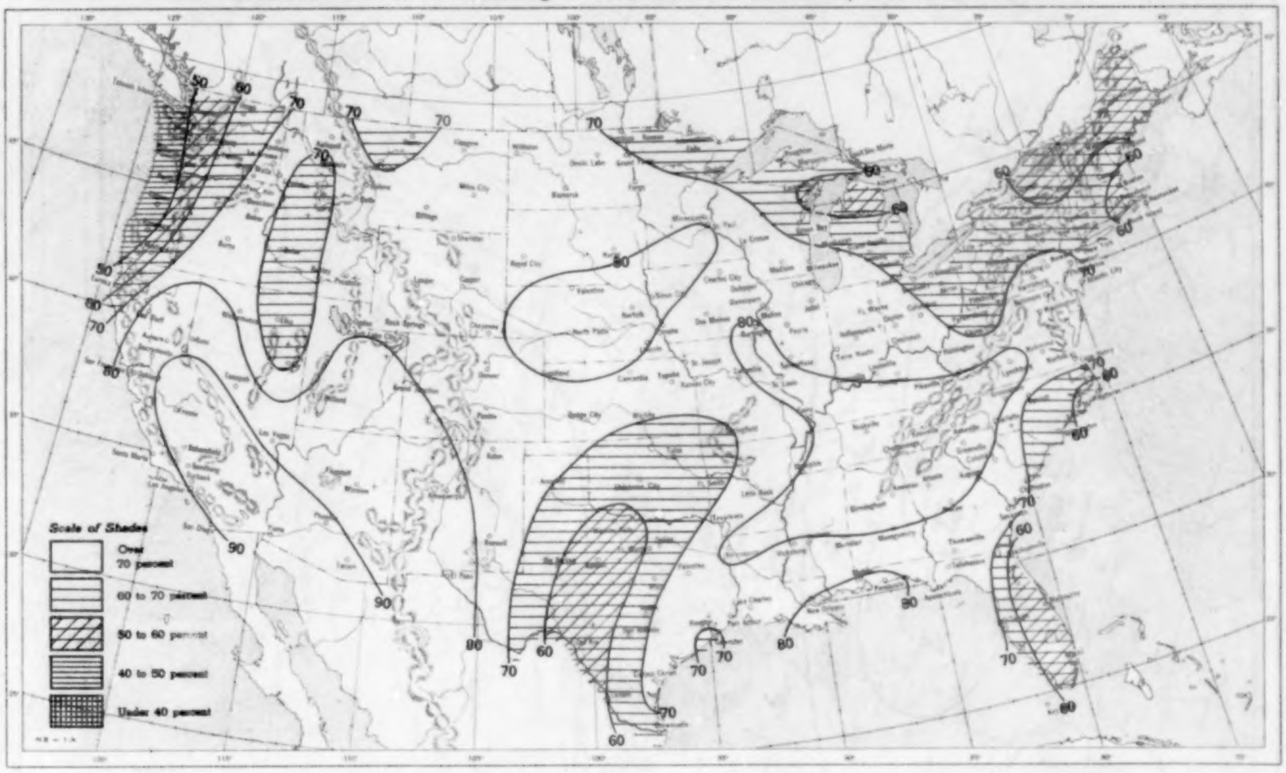


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, October 1953.

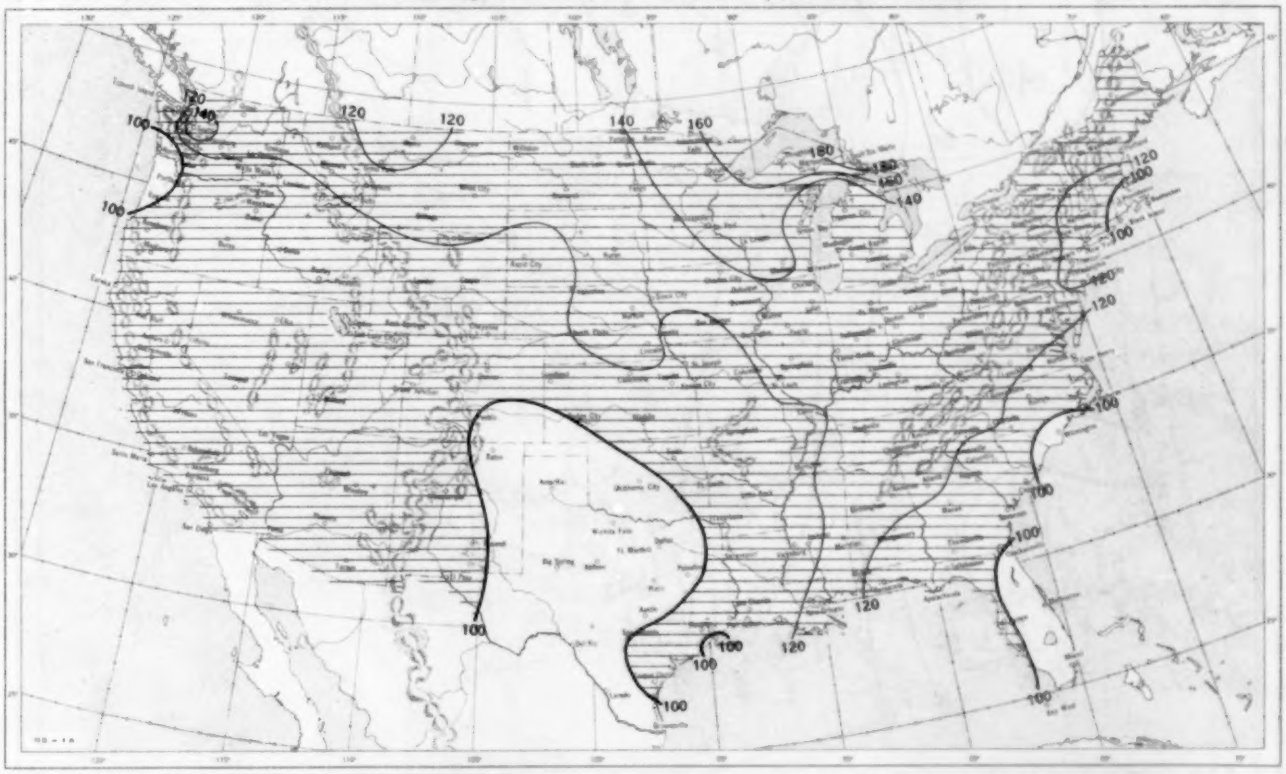


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, October 1953.



B. Percentage of Normal Sunshine, October 1953.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, October 1953. Inset: Percentage of Normal Average Daily Solar Radiation, October 1953.

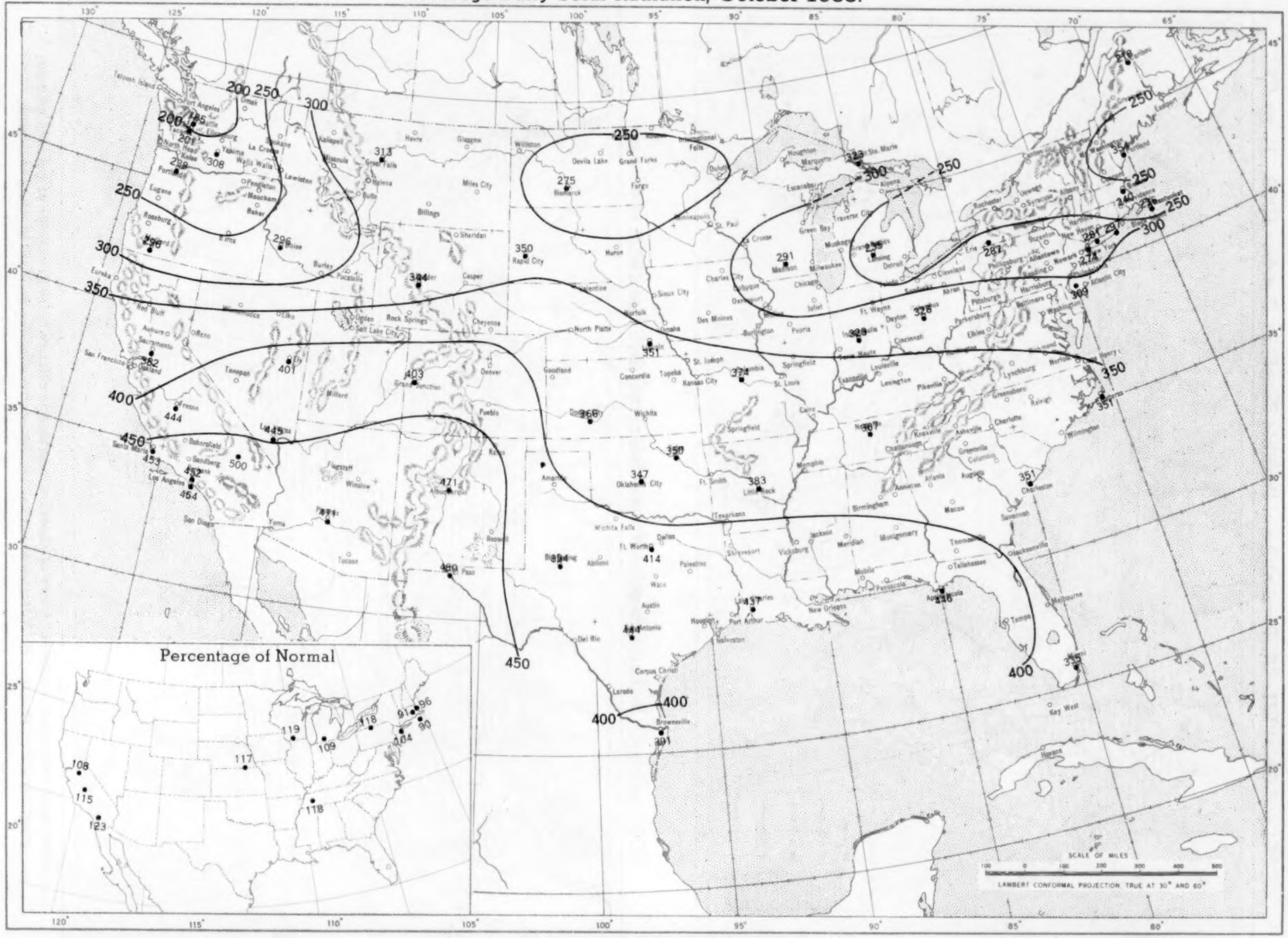
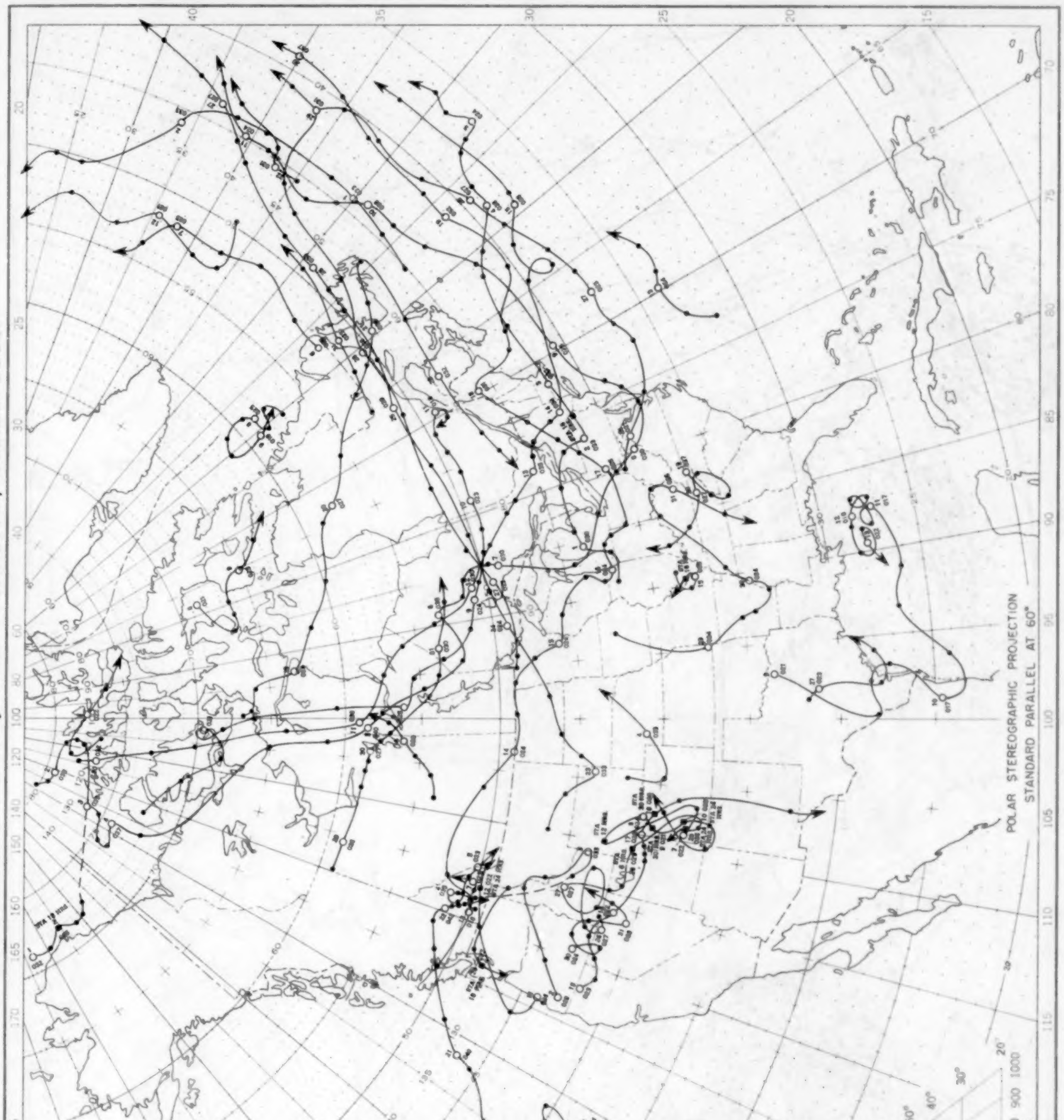


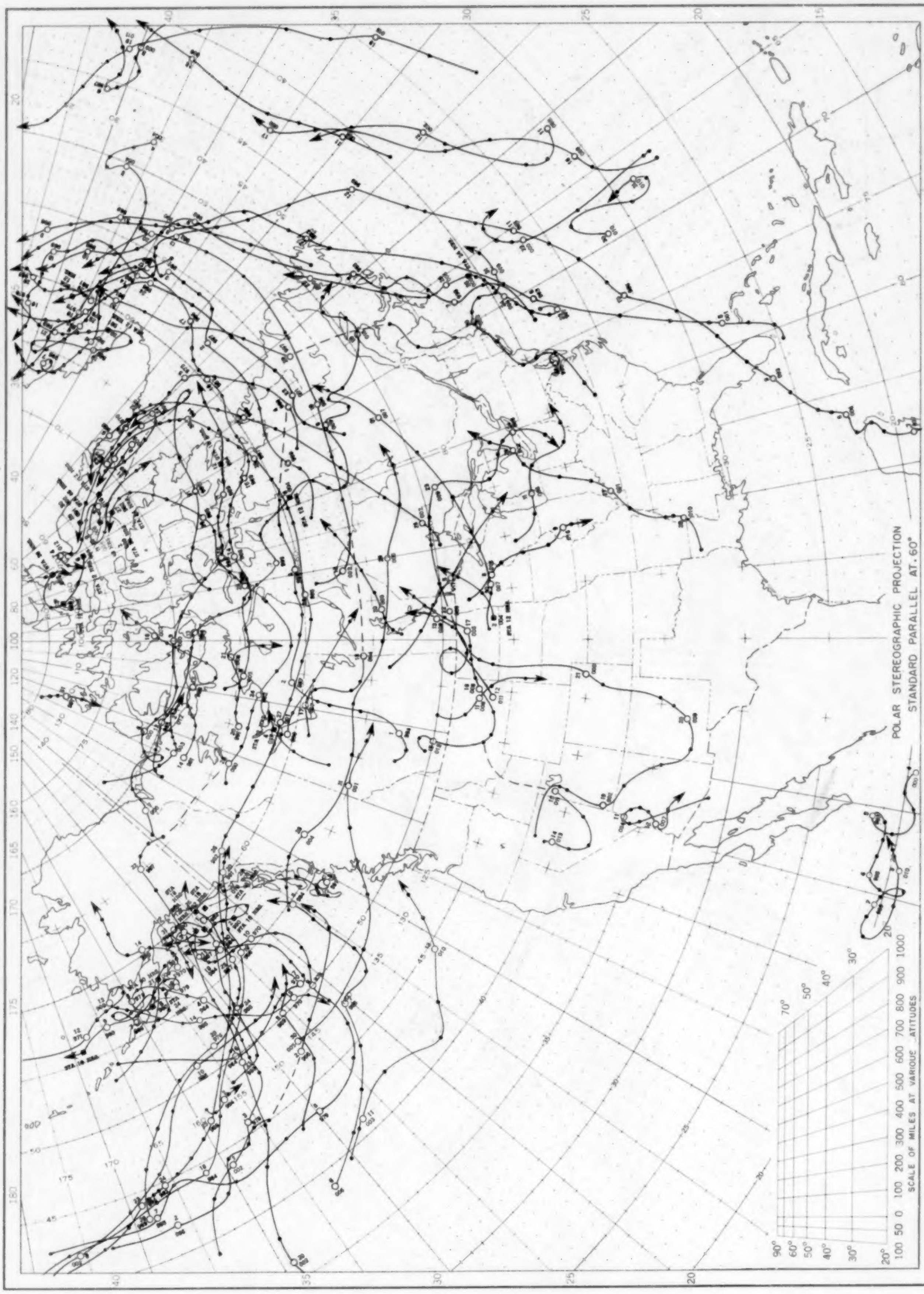
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm.$^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, October 1953.



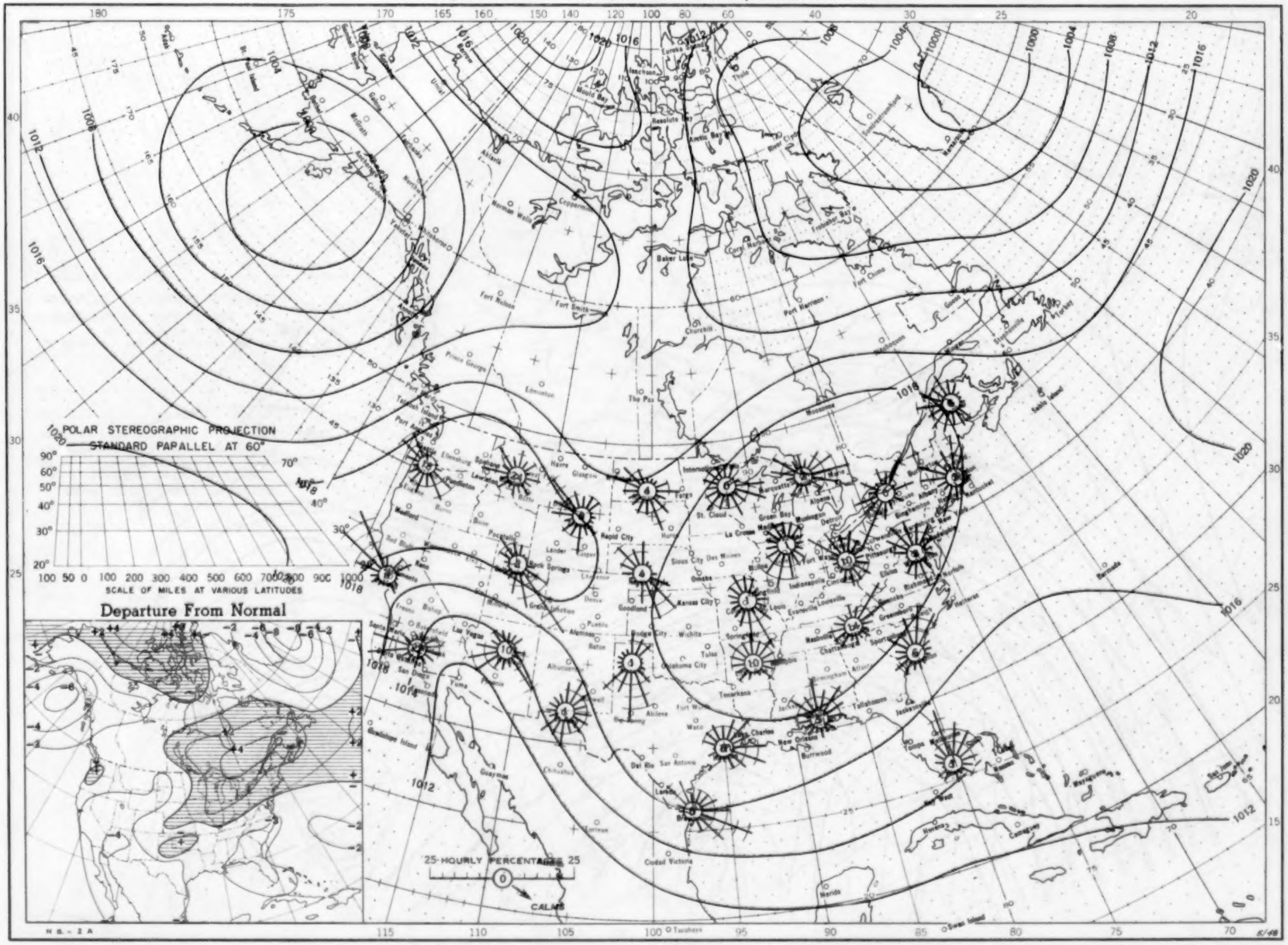
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, October 1953.



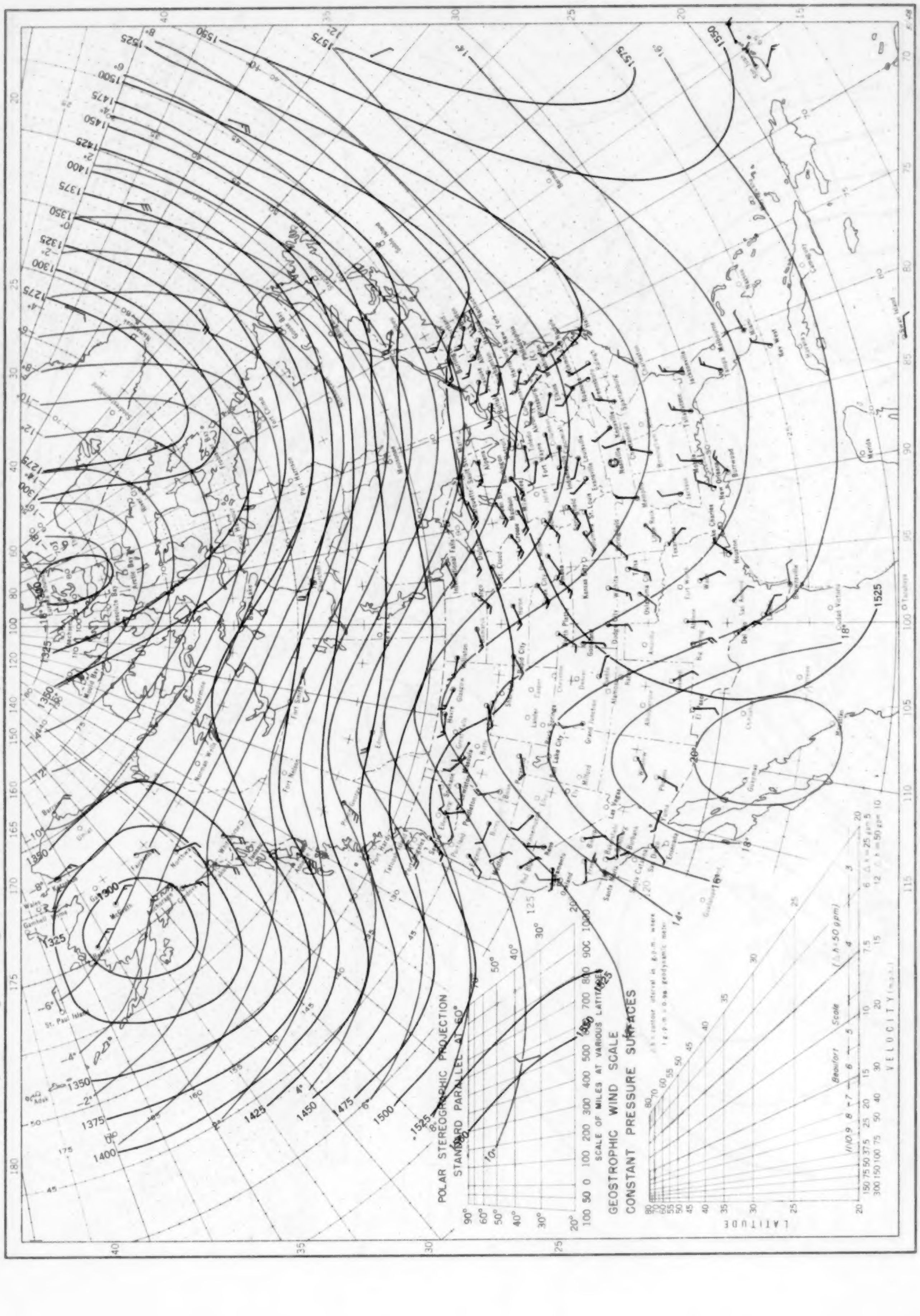
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, October 1953. Inset: Departure of Average Pressure (mb.) from Normal, October 1953.



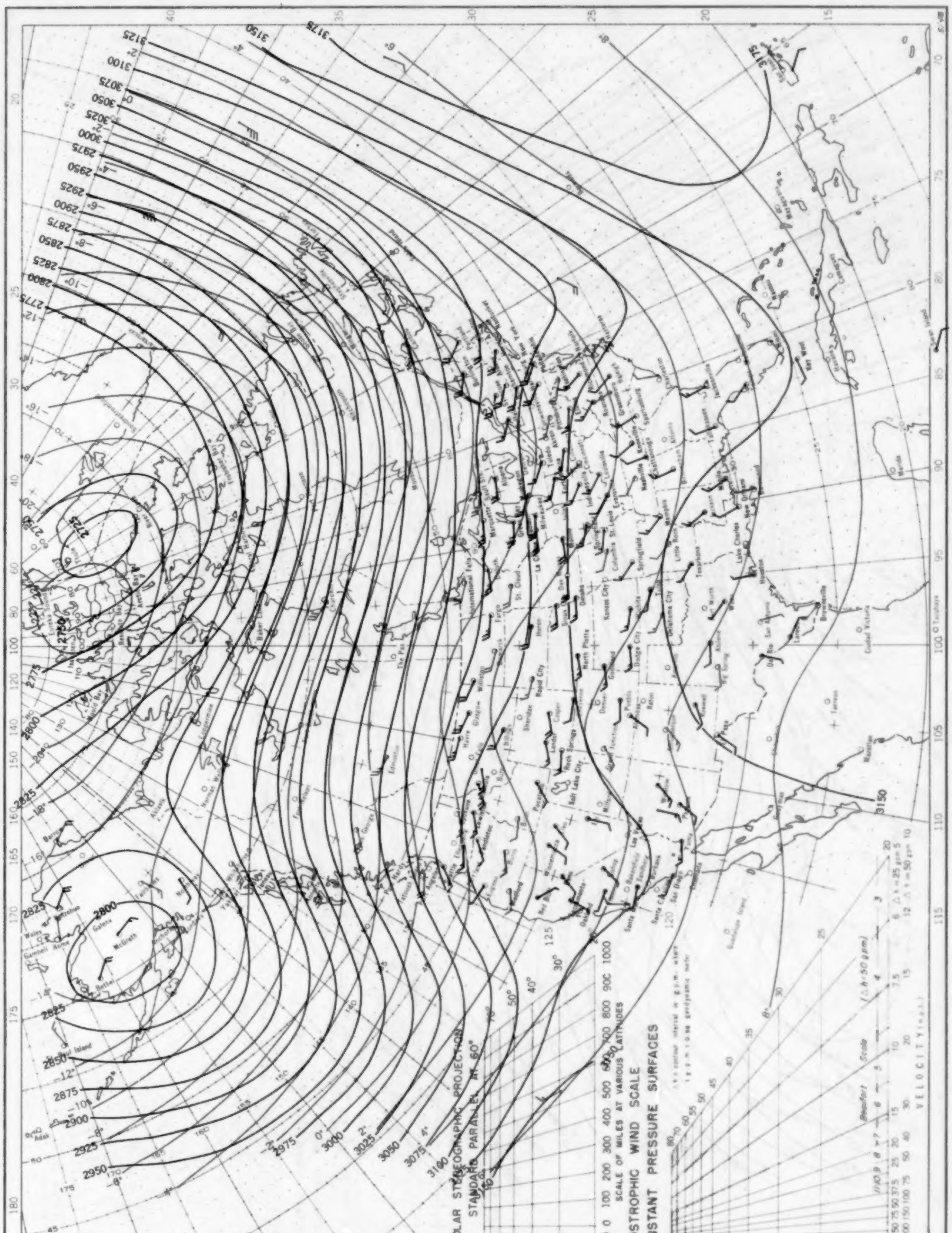
Average sea level pressures are obtained from the averages of the 7:30 a.m. and 7:30 p.m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), October 1953.



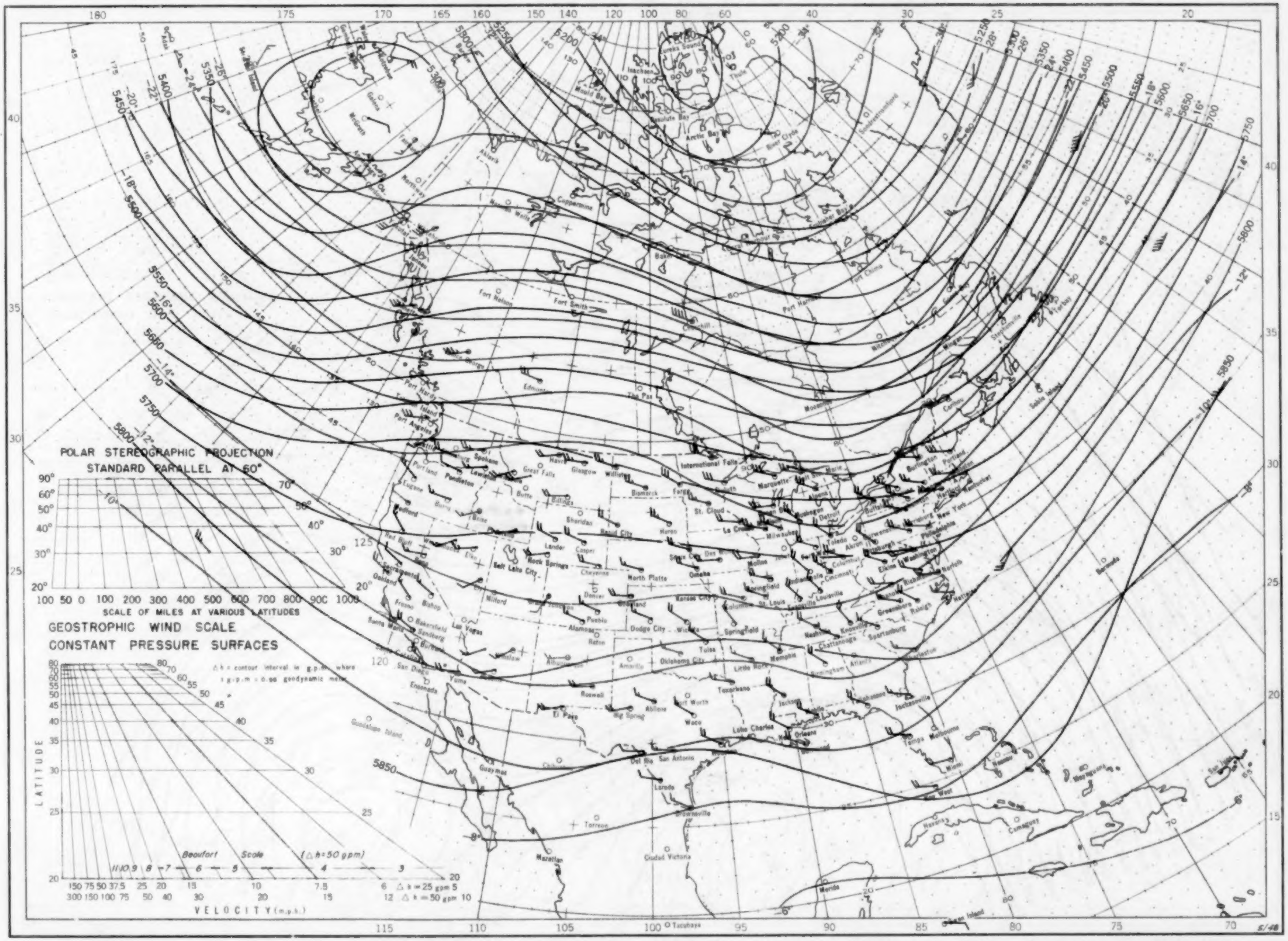
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), October 1953.



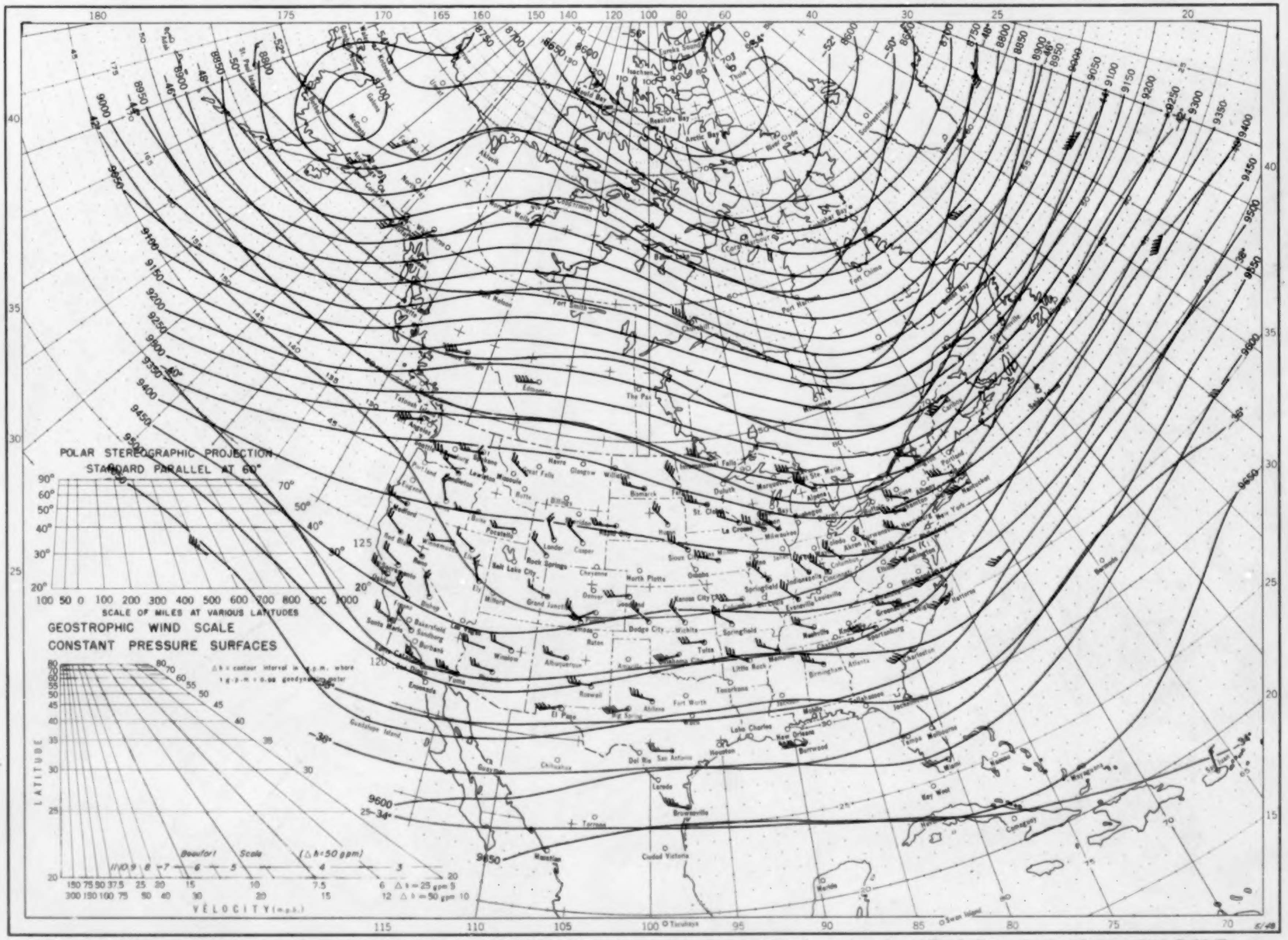
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), October 1953.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), October 1953.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.